Applying Mobile Consumer Neuroscience for Food Marketing
- the Special Case of fNIRS

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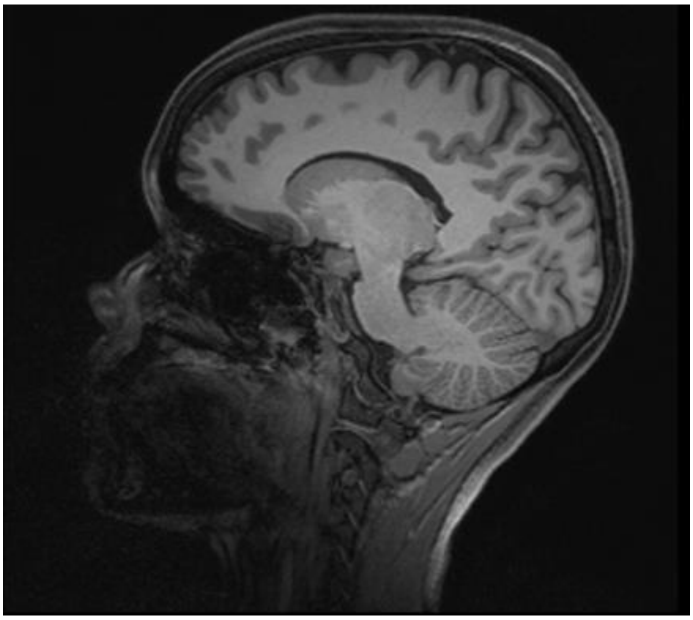
Für meine Familie, die Neugierde und Wissensdurst in mir entfacht hat.



Summary

This work demonstrates the potential of consumer neuroscience (CN) employed to empirically study consumer behavior in the field of food marketing. Two mobile CN tools – functional near-infrared spectroscopy (fNIRS) and eye-tracking (ET) – were used to study various aspects of consumer behavior. Due to the multisensory complexity of food decision-making processes, traditional marketing research methodologies are increasingly complemented by neuroscientific methods. Those are able to detect unconsciously occurring processes in consumers' minds. However, the neuroimaging tools used to date incur problems when examining consumer behavior in realistic environments and with real stimuli, which is crucial to investigate a wide variety of food related stimuli. As such, a new and innovative neuroimaging tool – fNIRS – was the special focus of this work. fNIRS promisingly indicates that it can overcome the mobility problem of the traditional methods used so far and that it can extend the application of neuroscientific tools to other population groups (e.g., children or overweight people). As such, it holds great potential for consumer neuroscience research.

The articles presented here demonstrate that it is possible to measure brand- and label-related neural prefrontal cortex (PFC) activation using fNIRS. They show that fNIRS can generally be used as an approach for hedonic taste evaluations because it is possible to present the sensory stimuli to participants in a natural way while also measuring brain activity. Also, they demonstrate the ability of fNIRS to capture processing through differently framed and primed labels in food contexts, and different emotional processing and perceptional processes are detectable, measurable, and can be made visible with fNIRS. Additionally, the articles present a first approach to link neural responses to underlying mental processes by tracing the PFC activity in relation to a health-labelling approach back to brain regions associated with reward evaluation and self-control. The perception of real products in a close-to-realistic environment was assessed with the use of a mobile head-mounted eye-tracker, showing that research in close-to-realistic food shopping settings is possible and should be followed up on.

Taken together, the articles point out that studies with greater ecological validity are possible with the help of mobile CN tools such as fNIRS and eye-tracking. Their integration and application expand the investigation of processes involved in food-related consumer behavior through the examination of additional internal (e.g., emotions) and external (real-world) influences. Thereby, they add to what is investigable with common marketing methods. This work increases consumers' data variance in economic studies and, as such, contributes to the further development of CN for food marketing.

This dissertation gives an overview of the fNIRS methodology in the context of CN, which attempts to facilitate easy access to the methodology, especially for researchers not coming from the field of neuroscience or psychology. For marketers, it delivers some inspiration concerning what might be possible with mobile tools and specifically with fNIRS, and how one could profit from the use of CN, but also what should be considered regarding ethical aspects.

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Abbreviations

BA	Brodmann area
BMI	Body mass index
CBF	Cerebral blood flow
CN	Consumer neuroscience
BOLD	Blood-oxygen-level dependence
dlPFC	Dorsolateral prefrontal cortex
ECG	Electrocardiogram
EDA	Electrodermal activity
ET	Eye-tracking
fEMG	Facial electromyography
fERS	Facial expression recognition
fNIRS	Functional near-infrared spectroscopy
fMRI	Functional magnetic resonance imaging
GSR	Galvanic skin response
HWM	Health warning messages
MPE	Marketing placebo effect
NCD	Non-communicable diseases
OFC	Orbitofrontal prefrontal cortex
PACE	Physical activity calorie equivalent
PFC	Prefrontal cortex
POS	Point of sale
SPM	Statistical parametric mapping
vmPFC	Ventromedial prefrontal cortex

1 Introduction

“Neither art nor science stands still in representing our visible and invisible worlds. Marketing, as both art and science, can’t stand still either”

- Gerald Zaltman -

Traditional marketing research methodologies are limited when it comes to measuring unconscious influences on consumers’ decision-making processes. These can be, e.g., the influence of values, attitudes, or emotions on choices, but also visual attributes of products such as packaging and color, the product placement on the shelf, or sensory stimuli (Bechara & Damasio, 2005; Javor, Koller, Lee, Chamberlain, & Ransmayr, 2013; Milosavljevic, Navalpakkam, Koch, & Rangel, 2012; Reimann, Schilke, Weber, Neuhaus, & Zaichkowsky, 2011). Consumers are usually not or only partially aware that they are influenced by a multitude of these external and internal factors that occur unconsciously and often even automatically inside the “black box” of their mind, because their individual decisions occur rapidly and often automatically (Bechara, Damasio, & Damasio, 2000; Cohen & Lesser, 2016; Fugate, 2007; Milosavljevic, Koch, & Rangel, 2011). Since classical marketing research methodologies focus retrospectively on conscious and rational observations or on direct reactions to marketing stimuli, they are not able to detect these influences at the moment they occur and are therefore limited concerning the research of these influences (Ariely & Berns, 2010; He, Freudenreich, Yu, Pelowski, & Liu, 2021; Hubert & Kenning, 2008; Stasi et al., 2018).

In this regard, marketing and consumer research has benefited primarily from collaboration with neighboring disciplines, such as psychology or neuroscience (Karmarkar & Plassmann, 2019; Plassmann, Ramsøy, & Milosavljevic, 2012). Through the integration and application of more objective, indirect, and in-the-moment measurement approaches, such as physiological and neurophysiological tools, the hope is to provide deeper and more far-reaching insights into consumers’ minds and to discover basic mechanisms of consumer behavior that are difficult to access using traditional behavioral measurement approaches (Ariely & Berns, 2010; Fugate, 2007; Hubert & Kenning, 2008; Lee, Broderick, & Chamberlain, 2007; Plassmann, Venkatraman, Huettel, & Yoon, 2015). Through this and due to the increasing technical possibilities, the resulting research field consumer neuroscience (CN) has generated increasing interest and excitement during the last 15–20 years (Plassmann et al., 2012). Besides a growing body of research in this field, leading market research companies are also integrating it into their portfolios (e.g., Nielsen, Ipsos, Deloitte, Millward Brown) (Plassmann et al., 2012; Shaw & Bagozzi, 2018; Stasi et al., 2018).

The increasing utility of methods from CN is expected to be very promising, especially against the background of the multiple social crises (climate, obesity, Covid-19, etc.). E.g., food consumption serves not only the satisfaction of a physiological need because it is essential for survival (Rangel, 2013), but it also affects the environment, food security, and human health (Alsaffar, 2015; Myers et al., 2013; Nemecek, Jungbluth, i Canals, & Schenck, 2016). However, it is a complex and multidimensional phenomenon that is not yet completely understood and therefore difficult to cover in its entirety in traditional consumer research (Stasi et al., 2018). A better understanding of the aspects and effects influencing consumers' behaviors and decision-making processes related to food and nutrition through the application of CN could therefore have great potential to influence these crises and opens up more opportunities to guide consumer behavior.

CN uses multiple tools to study consumer decision-making and behavior. For one thing, these are approaches, such as eye-tracking (ET), electrodermal activity (EDA), or electrocardiogram (ECG), used to measure vital physiological functions and reflexes (Alvino, Pavone, Abhishta, & Robben, 2020). Such devices examine autonomous functions of the body (e.g., eye-movement, heartbeat) and thereby help to understand people's biological reactions to different stimuli, but they cannot measure consumers' brain activity and the underlying cognitive processes (Alvino et al., 2020). Several neuroscientific imaging techniques are used to measure consumers' brain activity, where functional magnetic resonance imaging (fMRI) represents the methodological gold standard to date (Lee, Chamberlain, & Brandes, 2018). fMRI studies are helpful to understand which brain areas are involved in the decision-making processes in general. However, fMRI has some weaknesses when it comes to applied consumer behavior research, e.g., related to food and nutrition processing (Kopton & Kenning, 2014). The immobility of the fMRI system limits it to an exclusive use in the laboratory, which has associated constraints for realistic examination environments. Additionally, the possibility of examining human behavior in a lying position only, with a high noise level and where the subject is restricted in movement, complicates the further applicability for CN. This represents one of the main challenges of CN so far – the limited ecological validity (Kopton & Kenning, 2014; Spence, 2016). It makes the integration and investigation of a wide variety of food-related stimuli more difficult, which, however, would be necessary to address the multisensory complexity of food decision-making processes described above. Other methods, such as electroencephalography (EEG), have advantages in this respect, but they also reach their limits, especially for mobile measurements (Ratti, Waninger, Berka, Ruffini, & Verma, 2017; Telpaz, Webb, & Levy, 2015).

This highlights the special need for CN solutions that reduce unnatural experimental settings to a minimum and that allow for more realistic presentations of the experimental stimuli. Mobile devices that can be applied in a more flexible manner in different environments can be a solution. In light of this, one possible approach could be the use of mobile eye-tracking devices as a method for investigating consumer behavior in realistic environments or directly at the point of sale (POS). ET in general is already widespread in consumer behavior research; however, research in real-world or close-to-realistic shopping settings related to food and nutrition is limited so far (Steinhauser, Janssen, & Hamm, 2019). Additionally, the novel brain imaging technique functional-near infrared spectroscopy (fNIRS) promisingly indicates to overcome the mobility problem of the methods used so far and could extend the use of neuroscientific tools to other population groups (e.g., children or overweight people), thereby increasing the ecological validity and making it a potentially valuable and promising tool for CN research (Kopton & Kenning, 2014; Meyerding & Mehlhose, 2020). In fact, initial scientific work indicates that fNIRS is suitable for application-related use in the field of consumer research and, in particular, in the area of food and nutrition (Krampe, Strelow, Haas, & Kenning, 2018; Meyerding & Mehlhose, 2020; Meyerding & Risius, 2018). However, to date, there is a lack of studies that have actually applied the methodology to research questions in food- and nutrition-related consumer behavior processes. Therefore, the potential of fNIRS for food-related contexts is yet not well-known (Minematsu, Ueji, & Yamamoto, 2018). Similarly, it is not yet clear in which areas of consumer research for food marketing fNIRS can be used best and what applications might be promising and what some limitations are concerning the application of fNIRS. Furthermore, it remains unknown which additional value fNIRS has for this context compared to other mobile methods of CN.

Resulting from this, this thesis aims to demonstrate the empirical potential of the two CN methods – fNIRS and ET – to study consumer behavior in the field of food marketing. Both tools allow for mobile investigations and realistic stimuli presentations with respect to the ecological validity of food-related decision-making processes and at the place where consumer behavior takes place – at the POS. This increases the ability to address the multisensory complexity of food decision-making processes. The articles presented here thereby shed light on the general questions about whether and how mobile CN tools, and especially fNIRS and ET, can add value to traditional marketing research, and how they can be validated against other methodologies of socio-empirical research. As such, this work is intended to contribute to the further development of CN for food marketing through the use of mobile methodologies that can increase the ecological validity of CN studies.

Additionally, this thesis aims to provide an special overview of the use and characteristics of the CN tool fNIRS for food marketing and to place it in the overall context of CN. It does so specifically by providing a systematic investigation and demonstration of possible applications and fields of use for fNIRS in the area of consumer behavior in food- and nutrition-related marketing. The included articles show the feasibility of fNIRS for CN research and offer special insights into possible application options of fNIRS for the areas of brand and label marketing, sensory marketing, and health marketing. They furthermore highlight challenges and limitations of the fNIRS methodology for these special contexts.

Hence, this dissertation contributes to research and practice alike. For research, the dissertation gives an overview of the fNIRS methodology in the context of CN and delivers insights into the questions whether and how to use it to study consumer behavior. This facilitates an easy access to the methodology, especially for researchers not coming from the field of neuroscience or psychology. For marketers, it delivers some inspiration concerning what might be possible with mobile tools and specifically with fNIRS, how one could profit from the use of CN, and what should be considered in terms of ethical aspects.

To achieve the objectives presented above, the work is structured as follows: The first chapter presents the relevance of the topic, the existing research gaps, and the overall objective of this thesis. The second chapter explains the conceptual background and the concept of CN. It deals with the existing methodological procedures of CN, with special consideration of fNIRS. Its mode of operation, technical parameters, as well as the advantages and disadvantages compared to other imaging methods are explained. Based on this, the basic neuroanatomical knowledge of the brain region important for CN and fNIRS – the prefrontal cortex (PFC) – is presented. The following third chapter is dedicated to the research outline. In doing so, the content of the individual contributions is explained and their contribution to answering the research question is stated. The fourth chapter contains five articles and serves to demonstrate the empirical potential of fNIRS and ET to study consumer behavior in food-related contexts. The fifth and final chapter summarizes and discusses the findings once again and highlights their scientific and practical implications as well as the need for further research.

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2 The Concept of Consumer Neuroscience, Its Neuroscientific Tools, and fNIRS

2.1 Conceptual Background of Consumer Neuroscience

Today, human behavior is no longer seen as a purely rational consideration of utilities, but rather as a complex interplay of different variables and unconscious and automatic processes that involves and influences behavior (Bechara & Damasio, 2005; Kenning & Plassmann, 2005; Loewenstein, Camerer, & Prelec, 2005). This is why research at the interface of different disciplines has gained considerable interest in recent years (Plassmann et al., 2012). New fields of research, e.g., neuroeconomics, have emerged as a result. They integrate neuroscientific methodologies and tools into the investigation of economic problems with the attempt to transfer neuroscientific findings to economic sciences and the respective disciplines (Bossaerts & Murawski, 2015; Hubert & Kenning, 2008; Kenning & Plassmann, 2005; Loewenstein et al., 2005). The central assumption is that an advanced understanding of the biological processes of human behavior in general leads to improved explanatory models of human behavior in economic contexts and a unified theory of human behavior (Kenning, 2014; Kenning & Plassmann, 2005).

CN, as a sub-area of neuroeconomics, focuses on the associated processes of consumer behavior and their psychological meaning that take place in the brain (Hubert & Kenning, 2008; Lee et al., 2007). In contrast to neuroeconomics, which focuses generally on the question of how consumers make choices, CN deals with the influences that occur at different levels of behavior (e.g., individual vs. social behavior) and which might affect the balance between internal and external preferences (Breiter et al., 2015). It is an interplay of marketing that provides: theoretical and managerial research problems, with neuroscience that examines the functional anatomy of the human brain, neuroscientific methods that support the detection of the underlying conditions and processes associated with it, as well as with psychology that delivers behavioral or psychological theories, models, and experimental designs (Plassmann et al., 2012; Reimann et al., 2011). Additionally, CN derives behavioral predictions, concepts, and models that are generated from neuroscientific theories and research and tests it in economic contexts (Lee et al., 2007; Lee et al., 2018). As such, it becomes possible to provide new insights into understanding how and why consumers interact in the marketplace (Cherubino et al., 2019; Lim, 2018). All this is aimed to increase the explained variance between existing theories in the classical marketing field and actual observed behavior, as well as to develop a neuropsychological theory to understand consumer behavior (Karmarkar & Plassmann, 2019; Plassmann et al., 2012).

While scientific research often focuses on the consumer's point of view, aiming to better understand and explain his/her behavior, commercial applications, e.g., by market research companies, apply findings to sell a product or to gain profit through the use of such tools. This has led to misunderstandings in public and the scientific perception in the past. Since commercial applications often do not apply the same standards of a scientific nature as in studies that do not pursue a commercial goal (Javor et al., 2013), Kenning et al., for example, suggest using the term ‘‘consumer neuroscience’’ for the scientific proceeding of this research approach and to use ‘‘neuromarketing’’ for the application of these findings in managerial practice, but to not use these two terms interchangeably (Hubert & Kenning, 2008).

2.2 Consumer Neuroscience – Contributions, Potential, and Challenges

CN presents visible, audible, olfactory, or gustatory stimuli to participants during experiments (e.g. in Cha Kyoung, Suh, Kwon, Yang, & Lee Eun, 2019; de Wijk et al., 2018; Kokan et al., 2011; Reimann et al., 2011; van den Bosch et al., 2014; van der Laan, de Ridder, Viergever, & Smeets, 2011; van Rijn, de Graaf, & Smeets, 2017). It measures the activity in the human nervous system related to the presented stimuli, e.g., with fNIRS, but it can also include the measurement of psychophysiological parameters, e.g., eye movements with eye-tracking technology (a more detailed description of the methodology and tools can be found in Chapter 2.3), (e.g. Bialkova, Grunert, & van Trijp, 2020; Krampe, Gier, & Kenning, 2018; Meyerding & Risius, 2018; Reimann et al., 2011). The brain's activation during an experimental task is then compared to its activation during a control task (Meyerding & Risius, 2018). This makes it possible to draw conclusions about neural activations of different brain areas associated with the specific task (Reimann et al., 2011). The advantages and achievements of CN compared to existing methodologies will be examined in more detail in the following. Subsequently, the challenges that CN is facing will be described.

- *CN offers more complete data:* Traditional consumer research techniques (e.g., self-reports, questionnaires) rely on the ability of the participants to retrospectively remember and describe thoughts, habits, feelings, and so on. However, human behavior is influenced to the largest part through unconsciously occurring effects. CN helps to differentiate between conscious and unconscious conditions and processes that take place during the observed concepts (Hubert & Kenning, 2008; Lee et al., 2007; Loewenstein et al., 2005; Reimann et al., 2011).

- *CN offers more objective data:* Neurophysiological data is insensitive to the biases that are often problematic in subjective methods of valuation, e.g., social desirability or strategic behavior. People's biological responses to stimuli are usually not under their voluntary control, and people cannot consciously influence their brain activity. Therefore, the acquired data is not influenced by personal attributes and can be considered more objective (Hubert & Kenning, 2008; Loewenstein et al., 2005).
- *CN allows simultaneous in-the-moment measurements:* Not all effects or reactions to stimuli might be stable over time, and they can occur in parallel, which makes it difficult to reconstruct them afterwards. CN eliminates, e.g., the risk of a recall bias. Further, it allows to differentiate between processes that individuals may subjectively perceive as similar, but which they objectively process not simultaneously (Hubert & Kenning, 2008; Lee et al., 2007; Reimann et al., 2011; Solnais, Andreu, Sánchez-Fernández, & Andreu-Abela, 2013).
- *CN measures implicit processes such as emotions:* CN gains information, e.g., about emotional reactions to stimuli in the brain. This is very important to identify in order to improve the knowledge concerning the role of emotions with regard to their influence on decision-making (Hoshi et al., 2011; Kreplin & Fairclough, 2013; Lim, 2018).
- *CN increases knowledge about underlying psychological processes:* Through the identification of brain areas that are related to the marketing stimuli or phenomena observed, CN offers more fundamental insights into possible underlying psychological processes that influence consumer behavior, such as learning, memory, attention, or motivation (Cherubino et al., 2019; Kenning, 2014; Lim, 2018; Plassmann et al., 2015; Shiv et al., 2005).
- *CN comes closer to constructs of interest:* The explorative character of CN goes beyond the traditional measurement scales for liking, agreement, or attitude and has the potential to yield new, unpredictable results. It can advance knowledge and examine different phenomena and constructs of interest, e.g., reward vs. punishment, social behavior consequences, framing, priming, or self-control (Cherubino et al., 2019; Han, Boachie, Garcia-Garcia, Michaud, & Dagher, 2018; Niedziela & Ambroze, 2020; Peters & Büchel, 2010; Rosenblatt et al., 2018a; Rosenblatt et al., 2018b; Shiv et al., 2005; Silveira, Fehse, Vedder, Elvers, & Hennig-Fast, 2015).
- *CN expands (existing) marketing theories:* CN offers access to hidden data which could provide the basis for generating new marketing theories or revise old knowledge by providing insights into underlying mechanisms, differentiating between contributing

psychological processes, and measuring implicit processes that are difficult to access using other approaches. This can lead to a greater explanatory power of human behavior (Hubert & Kenning, 2008; Knutson, Rick, Wimmer, Prelec, & Loewenstein, 2007; Lim, 2018; Plassmann et al., 2015; Shiv et al., 2005). One example for this is the first-choice brand effect, which, contrary to the previous assumption that a range of alternatives (e.g., brands) can satisfy a customer's needs, shows that only the favorite brand is able to emotionalize the decision-making process (Deppe, Schwindt, Kugel, Plassmann, & Kenning, 2005; Krampe, Gier, et al., 2018).

- *CN predicts behavior:* Brain measures can be used to predict outcomes, e.g., purchasing decisions or food choices. This was already done over longer timescales and in ways that go beyond what was previously possible with self-reported data. This brain-as-predictor approach can be used to reveal the connections between neural activity from laboratory contexts and actual real and valid outcomes (Berkman & Falk, 2013; Falk, Berkman, & Lieberman, 2012; Plassmann et al., 2015).
- *CN identifies individual differences*: Brain activity is influenced by expectation effects, e.g., pricing effects or biases in the way products are presented, (marketing) placebo effects, or framing and priming effects. CN can be helpful in identifying individual differences in consumers’ reactions to different types of stimuli that influence their behavior (Ariely & Berns, 2010; Bruce, Crespi, & Lusk, 2015; Enax & Weber, 2015; Francisco et al., 2015; McFadden et al., 2015; Plassmann et al., 2015; Shiv et al., 2005).

So far, CN has produced important fundamental knowledge and first significant results for marketing and consumer behavior (Ariely & Berns, 2010; Kenning & Plassmann, 2005; Lee et al., 2018). In order to accelerate this relatively young discipline, it is essential that CN faces up to the existing challenges, which is mainly the limited ecological validity of its studies (Ariely & Berns, 2010; Kopton & Kenning, 2014; Spence, 2016). The further progress of CN will depend on the extent to which basic neuropsychological insights have practical and theoretical applications in marketing and consumer behavior research and can provide additional value for applied and real-life oriented research questions, e.g., for understanding consumers’ food- and nutrition-related behavior (Karmarkar & Plassmann, 2019; Plassmann et al., 2015; Stasi et al., 2018). As such, basic research must now be increasingly expanded to include real-life marketing- and consumer-specific theories. Mobile and flexible neuroimaging tools that can be used in realistic environments, e.g., at the POS, could contribute to such an alignment since the limited ecological validity can also be related to the mobility problem of the methods used so far (Kopton & Kenning, 2014). Thanks to technological progress, the range of methods is increasingly growing and expanding and further increases the possible uses and applications for CN experiments, especially towards more application-related research. At the same time, this means lower costs and less effort, making the use of such technologies more attractive and user-oriented (Alvino et al., 2020). Such attempts will be shown in the articles presented in this dissertation, where the mobile neuroimaging tools fNIRS and ET were used to study consumer behavior.

2.3 Neuroscientific Tools for Consumer Neuroscience

The methods used in CN do usually not differ from those classically used in neuroscience. Therefore, they are mainly classified according to their type of measurement for the respective method mechanism, which is the distinction between *psychophysiological* and *neurophysiological* (brain imaging) tools. In order to better understand and delineate the methods used in this dissertation, a comparative overview of CN methods will be given before focusing on fNIRS technology and explaining the most important brain areas for the investigation with fNIRS – the prefrontal cortex and its functions.

Psychophysiological tools can measure peoples' biological reactions and responses to a stimulus in or resulting from the peripheral nervous system. This can be vital physiological functions, such as the heartbeat, but also voluntary and involuntary reflexes, e.g., eye movements. Examples for physiological tools are eye-tracking, electrodermal activity, or facial expression recognition (for more details on the methodologies, see Table 1). Most of these tools are already widely used because they allow for simple real-life measurements; however, they are limited in terms of their informative value (Alvino et al., 2020).

Neurophysiological or brain imaging tools measure and record brain activity and produce a pictorial representation of it. They inform about the underlying or ongoing neural activity of related aroused brain regions by, e.g., marketing stimuli. They can be further divided into tools that measure the *electrical brain activity* and those that measure the *metabolic brain activity* (Alvino et al., 2020). Electrophysiological tools measure the changes in the electrophysiological activity of the brain, i.e., the direct activity of the neurons and their action potentials, which results in a very high temporal resolution. In contrast, metabolic methods indirectly measure the substances associated with neural activity under the assumption that active or activated brain regions require more energy and thus more oxygen. The differences (e.g., optical or magnetic) between oxygen-deficient and oxygen-rich blood are then used as a physiological feature to measure neural activity. This results in a satisfactory spatial resolution but a less satisfactory temporal resolution (Kenning, Plassmann, & Ahlert, 2007). For details of these methodologies, please refer to Table 1.

Some authors also include behavioral measurements (e.g., the observation and recording of participants performing a special task, the measurement of reaction time with regard to an experimental task, surveys, self-reports) into the division of neuroscientific tools, even though they do not deliver unconscious bodily reactions or signals from the nervous system (Alvino et al., 2020). The reason for this is that these measurements reveal additional information about consumers, e.g., their subjective impressions or concerns, which can influence their bodily behavior and which are therefore important to know. This is additionally motivated through the interdisciplinarity of the research field that should use not only one but ideally several different measurement channels to gain a more holistic picture of consumer behavior. The articles presented in here used behavioral measurements as well; however, behavioral measurement approaches will not be discussed further since the focus of this work is on the actual neurophysiological procedures, which offer the greatest novelty and added value for the study of consumer behavior. Table 1 provides an overview of the neurophysiological and psychophysiological methods of CN that are classically used, with their respective advantages and disadvantages. It also discusses their suitability for mobile studies, as this is a focus of this work.

Table 1: Overview of consumer neuroscience tools

Classification	**Tool**	**Measurement**	**Description, advantages & disadvantages**	**Mobile use**
Psychophysiological Methods				
	Eye-tracking (ET)	Visual attention Fixations Pupil dilatation	Movement of the eye as indicator for neural activity + easy to handle + low cost - failure-prone	Stationary or portable, head-mounted devices available (e.g., glasses)
	Electrodermal activity (sometimes also galvanic skin response) (EDA, GSR)	Skin resistance Skin conductance Stress level Arousal	Change in electrical skin conductance & in autonomic tone with regard to the emotional state of the subject. + easy to set up & handle + low cost - very sensitive to artifacts - low individual usefulness	Portable
	Electrocardiogram (ECG)	Heartbeat Blood flow	Variance in heartbeat, pulse & electrical activity of the heart + easy to set up & handle + low cost + good temporal resolution - low individual usefulness	Portable
	Facial expression recognition or facial electromyography (fERS/fEMG)	Facial expressions	Measurement of facial expressions through the activity of individual facial muscles as metrics of subjects' emotions + easy to set up + low costs	Portable
Neurophysiological Brain Imaging Methods				
Electrophysiological activity	Electroencephalogram (EEG)	Brain activity to investigate cognitive processes (e.g., attention, arousal, emotion…)	Non-invasive measurement of electrical brain activity + excellent temporal resolution + relatively low cost + (quite) tolerant towards body movements - poor spatial resolution - only cortex, no deeper brain regions	Stationary, but wearable devices becoming more available

Metabolic activity	Functional magnetic resonance imaging (fMRI)	Brain activity to investigate which parts of the brain are involved in cognitive processes. Measures the blood-oxygenation-level-dependent (BOLD) response	Changes in magnetic properties of body tissues associated with cellular metabolism + high spatial resolution + deep brain regions - low temporal resolution - very expensive - visual stimuli preferred - complicated data analysis - ethical concerns	Stationary only
	Functional near-infrared spectroscopy (fNIRS)	Brain activity. Measures the BOLD response in response to changes in the relative levels of oxy-Hb and deoxy-Hb	Changes in oxygen saturation (coloring) of blood associated with cellular metabolism. + high tolerance to motion artefacts + relatively easy to handle + temporal resolution relatively good but lower compared to EEG + noise-free + low in cost - limited spatial resolution - no deeper brain regions	Stationary & mobile devices available

Following Cherubino et al., 2019; Kenning, 2014

2.4 Functioning of fNIRS

Due to the novelty of the fNIRS methodology, the mode of operation and the biological backgrounds will be explained by highlighting its benefits and limitations.

In 1977, Jöbsis was the first to use near-infrared light to make oxygen saturation changes of tissue visible (Jobsis, 1977). In 1985, Ferrari et al. pioneered in using the method for cerebral oxygenation (Ferrari, Giannini, Sideri, & Zanette, 1985). So far, the method has mainly been used in medicine and psychology. The first studies in an economic context took place near the 2010s, so the development of fNIRS measurements in general, but for CN specifically, is clearly still in the beginning stages (Luu & Chau, 2009).

The operating principle of fNIRS is based on the special properties of near-infrared light. Near-infrared light can pass through human tissue in a non-invasive manner, including the cortical tissue of the human brain. Today, near-infrared light with wavelengths between 650 nm and 950 nm is sent into the head for cerebral examination (Ferrari & Quaresima, 2012; Scholkmann et al., 2014). Due to the comparatively low absorption rate of water and hemoglobin in this wavelength range, biological tissue is relatively permeable to light (‘optical window’), which makes penetration of the underlying tissue possible (Quaresima & Ferrari, 2016). One uses light-emitting optodes and light-collecting detectors that are placed on the head with the help of a cap or headband. The light passes in u-shaped or banana-shaped form from the optodes through the tissue and is identified by the detectors when leaving the head. While in between, the main parts of the light are scattered and others are absorbed by oxy- and deoxyhemoglobin in the brain (Ferrari & Quaresima, 2012; Quaresima & Ferrari, 2016). The difference between the transmitted and emitted light provides information about the neural activity at the respective location in the tissue passed by the light. The process is visualized in Figure 1.

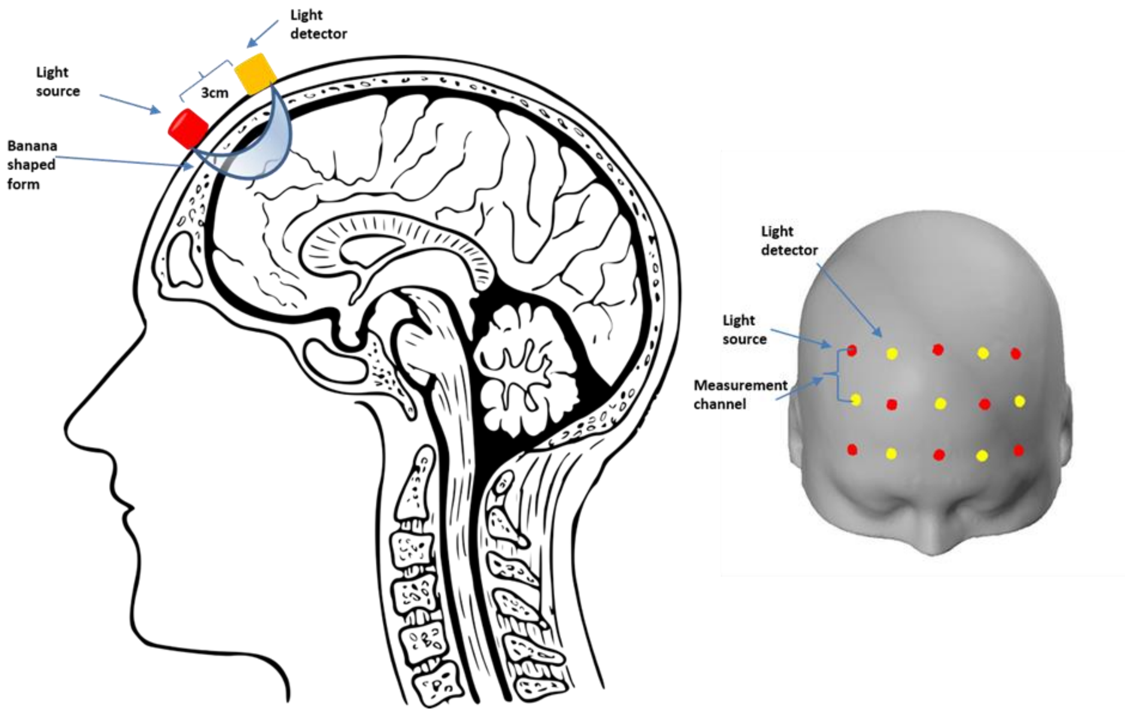

Figure 1: The light passes in banana-shaped form through the tissue. In between the light source (red) and the light detector (yellow) lies the measurement channel. Several channels represent the topographical layout covering the brain area of interest (here: prefrontal cortex). The sources and detectors are placed on a headband or whole head cap, which is not visible in this figure. Source: Own illustration.

As fMRI, fNIRS is also a metabolic measurement technique and uses the concentration changes of oxygenated and deoxygenated hemoglobin as a baseline parameter (Quaresima & Ferrari, 2016). The underlying biological process leading to this is called neurovascular coupling. In this process, brain activity, e.g., during a mental task, increases the metabolic demand for oxygen, leading to a stronger cerebral blood flow in this area to fulfill the demand. This hemodynamic response leads to a strong increase in oxyhemoglobin and a decrease in deoxyhemoglobin in these areas (Wolf et al., 2002). It is the change of oxygen saturation through the change of the cerebral blood flow that can be made visible and allows conclusions to be made about cortical hemodynamic processes in the brain (Meyerding & Mehlhose, 2020; Ferrari & Quaresima, 2012; Kenning et al., 2007). In fMRI and fNIRS, this is described as the BOLD effect (blood-oxygen-level dependency) through which the neuronal activities can be expressed. One of the main differences between the methodologies is that in fMRI, it is measured through the paramagnetic differences between oxy- and deoxyhemoglobin, while fNIRS uses the blood color changes in dependence with the oxygen content to make the brain activity visible (Ferrari & Quaresima, 2012).

An exact placement of the optodes and diodes on the head is necessary to localize the neural activity and to create a map of the brain areas. Their location is specified by the international 10–20 system, a method to describe and localize the EEG scalp electrodes with the aim of maintaining standardized study outcomes concerning the location of an electrode and the underlying area of the brain (for a detailed figure, please refer to article 4 in this thesis – Laves et al. 2021). The best penetration depth of the light can be achieved with a distance of 3 cm between optode and detector, but it also depends on the age of the subjects as well as the light intensity (Ferrari & Quaresima, 2012). The area in between an optode and a detector is called a (measurement) channel. For details, please see Figure 1. As such, a topographical layout can be created which allows the localization of brain activity and the mapping of the brain areas from the fNIRS measurements to standardized brain atlases. One of the best-known divisions and the one which is also used for the articles presented here is the cytoarchitectonic division according to Brodmann (Brodmann, 1909). He divided the brain into 52 parts which are referred to today as Brodmann areas (1–52). Areas 9–12 and 46 (dorsolateral and orbitofrontal) are particularly important for the prefrontal cortex, the area most important for studying CN with fNIRS (please refer to chapter 2.6 for a description of the PFC).

2.5 Advantages and Disadvantages of fNIRS

There are several advantages and disadvantages of fNIRS that are further elucidated in the following to provide a more detailed overview of the possibilities for the use of fNIRS, also in contrast to the other methodologies. It should be mentioned that there are stationary fNIRS systems as well as mobile fNIRS systems. As mobile measurement systems show greater potential to overcome the problems of ecological validity described above, the studies presented in this dissertation used a mobile fNIRS device. Many of the advantages and disadvantages described in the following therefore refer specifically to the mobile version of the technology:

Advantages of fNIRS

- Mobile fNIRS is flexible, portable, cable-free, and noise-free. It enables the use in real-world situations, in unconstrained environments, and for freely moving subjects (Balardin et al., 2017; Quaresima & Ferrari, 2016).
- fNIRS is very low in cost compared to fMRI measurements (Quaresima & Ferrari, 2016).
- fNIRS is comfortable and tolerant to body movement, and there are no restrictions concerning the test subjects, unlike in fMRI measurements (e.g., persons with a

pacemaker cannot participate due to the strong magnetic field) (Quaresima & Ferrari, 2016).

- The near-infrared light is harmless and allows for a non-invasive measurement of the brain activity (Quaresima & Ferrari, 2016).
- fNIRS allows for examination of the PFC, a brain region very important in CN, and the localization of specific brain regions is also possible (Quaresima & Ferrari, 2016).
- Real-time measurements are possible (Gateau, Durantin, Lancelot, Scannella, & Dehais, 2015; Quaresima & Ferrari, 2016).
- fNIRS can be combined with other measurement methodologies (ET, EEG, etc.) (İşbilir, Çakır, Acartürk, & Tekerek, 2019; Quaresima & Ferrari, 2016).
- fNIRS can measure oxy- and deoxygenated as well as total hemoglobin, while fMRI allows only the measurement of oxy-Hb. This permits an internal validation of data quality (Quaresima & Ferrari, 2016).

Disadvantages of fNIRS

- Until now, there have been no standardized application and analysis methodologies or procedures, which makes the comparison of studies and results challenging (Quaresima & Ferrari, 2016).
- fNIRS has a lower spatial resolution compared to fMRI, so the results do not provide detailed anatomical information (Ferrari & Quaresima, 2012).
- The temporal resolution of fNIRS is lower compared to EEG measurements (Ferrari & Quaresima, 2012; Quaresima & Ferrari, 2016).
- fNIRS only permits the examination of superficial cortical areas, and it is not possible to examine other and deeper regions that have been shown to be important for CN as well, e.g., the amygdala (Ferrari & Quaresima, 2012; Quaresima & Ferrari, 2016).
- Data can be highly influenced by extracerebral confounds (e.g., heartbeat) which needs to be considered in data analysis (Scholkmann et al., 2014; Tachtsidis & Scholkmann, 2016).
- Data acquisition can be influenced by dark hair, external light sources, and strong body and head movements, which requires special preparation for the experimental set-up. A stable contact between source/detector and skin is critical (Quaresima & Ferrari, 2016).

2.6 The Prefrontal Cortex

The PFC is one part of the frontal lobe and is located at the front of the brain. Generally, the brain’s frontal regions play a central role in cognition (Carlén, 2017). Complex cognitive functions, also called executive functions, e.g., attention and decision-making processes, as well as their associated emotion regulation, are attributed to the PFC (Carlén, 2017). As such, the PFC seems crucial for investigating, e.g., marketing-relevant problems (Knutson et al., 2007; Plassmann, O'Doherty, Shiv, & Rangel, 2008). Since it is a superficial brain structure, the PFC is also particularly well-suited for the examination with fNIRS. However, even though it is possible to assign functional roles to individual areas of the brain, it must be noted that the brain is an interconnected network and should therefore always be considered as a whole. Many functional constructs of interest also consist of subcortical brain regions that cannot be examined with fNIRS technology.

The PFC can be divided into several parts. The three main parts that fulfill important functions for CN should be described in more detail: The orbitofrontal cortex (OFC), the dorsolateral prefrontal cortex (dlPFC), and the ventromedial prefrontal cortex (vmPFC) (Hubert & Kenning, 2008). For a visualization, please see Figure 2. The **dorsolateral part** is mainly responsible for cognitive actions and rational decision-making (Hubert & Kenning, 2008), e.g., estimating a willingness to pay (Plassmann, O'Doherty, & Rangel, 2010) or deciding about multi-attribute choices (McFadden et al., 2015), but it is also involved in the cognitive control over emotions (Rilling, King-Casas, & Sanfey, 2008). The **orbitofrontal part** is also included in decision-making but is more often associated with the evaluation of incoming stimuli from different types because it encodes their valences (Hubert & Kenning, 2008). As such, the OFC seems to be part of the complex reward and punishment evaluation system, which seems to be not only activated through food or other bodily stimuli, but also through brands, product preferences, and other attractive items (Erk, Spitzer, Wunderlich, Galley, & Walter, 2002; Kringelbach, 2005; Kringelbach & Rolls, 2004; McClure et al., 2004). The **ventromedial part** of the PFC seems to be important for the integration and regulation of emotions into the decision-making process (e.g., risk and fear) and, as such, it can be associated with preference building, e.g., when it comes to brands, products, or sensory information. However, it also seems to integrate social norms or morality into the decision-making process (Hubert & Kenning, 2008; Rilling & Sanfey, 2011; Solnais et al., 2013).

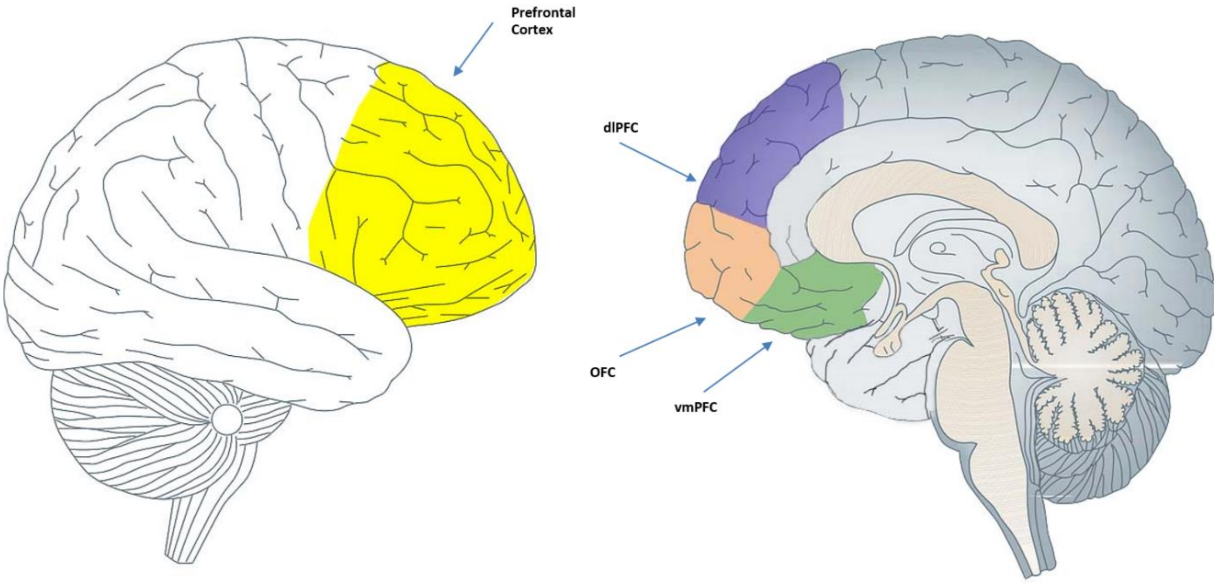

Figure 2: The prefrontal cortex and its three main subdivisions. Source: Own illustration by Konstanze Laves.

Note: The illustration does not represent anatomically correct boundaries but only serves as an overview.

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3 Research Outline – Systematic Classification of the Articles and their Contribution

This dissertation includes five articles that analyze the feasibility of fNIRS and ET for CN research while they are applied to three different fields of food marketing, namely to brand and label marketing, to sensory marketing, and to health marketing.

It contributes to solving the problem that the further development of CN requires an increase in the evoked ecological validity, e.g., through the use of mobile methods that allow investigations with respect to the realistic environment of consumer behavior. On a smaller scale, this thesis contributes to the field by providing an overview of the use and characteristics of the CN tool fNIRS employed for studying consumer behavior in the field of food and nutrition marketing, and to place it in the overall context of CN. Table 2 provides an overview of the research goals, the research approach, the key findings, and the key contributions of all articles. The articles are described in more detail in the following:

Table 2: Overview of the research goals, the research approach, the key findings, and the key contributions of all articles.

Articles	Research goal	Research Approach	Key findings	Key contributions
Article 1 (A1): *Can neuromarketing add value to the traditional marketing research? An exemplary experiment with functional near-infrared spectroscopy (fNIRS)* **Authors:** Stephan Meyerding & Clara Mehlhose **Status:** Published in '*Journal of Business Research'* (2020)	• To examine the feasibility of mobile fNIRS • To discuss whether neuromarketing can enrich traditional marketing research	Survey, Coke taste test and 2 exemplary fNIRS experiments: • Food label: Organic and regional food label • Coke taste test: Coke brands and Coke taste test	• Brand- and label-related PFC activity can be measured with fNIRS • Feasibility of fNIRS was shown • fNIRS is a highly promising tool for consumer neuroscience	• Opportunities and challenges of neuromarketing in general • Realistic (sensory) stimuli presentation is possible • Potential and advantages of fNIRS for neuromarketing and economic research, e.g., for brand and label marketing
Article 2 (A2): *Assessing label frames and emotional primes in the context of animal rearing – Response of an explorative fNIRS study* **Authors:** Clara Mehlhose & Antje Risius **Status:** Published in '*Sustainability'* (2021)	• To examine whether fNIRS can detect emotional processing in food contexts • To show the ability of fNIRS to measure neural reactions to differently framed and primed food labels	fNIRS experiment: • Labels claiming absence or presence of quality aspects • Emotional primes of idyllic vs. oppressive pictures of poultry production	• Ability of mobile fNIRS to detect neural effects of framing and priming in food contexts • Idyllic prime increased PFC activity • Process information should be anchored in a positive manner to highlight an additional product quality	• fNIRS is an appropriate neuroimaging tool to capture emotion-related processing through labels and primes in the context of agriculture and food systems
Article 3 (A3): *Signs of warning: Do health warning messages on sweets affect the neural prefrontal cortex activity?*	• To examine consumers' perceptions of two graphical health warning messages (HWM) on sweets • Neural responses to the HWM	Survey and fNIRS experiment • Shocking pictures vs. stop symbols as HWM on sweets	• HWM evoked emotional reactions among participants • HWM as a possible intervention strategy to combat obesity	• Validation of fNIRS against other elements of socio-empirical research, here: qualitative research • First approach of linking neural responses to

Authors: Clara Mehlhose & Antje Risius **Status:** Published in '*Nutrients'* (2020)	• Subjective perception of HWM		• Increased PFC activity in regions associated with reward evaluation and self-control	underlying mental processes
Article 4 (A4): *Sensory Measurements of Taste: Aiming to Visualize Sensory Differences in Taste Perception by Consumers – An Experiential fNIRS Approach* **Authors:** Konstanze Laves, Clara Mehlhose, Antje Risius **Status:** Published in '*Journal of International Food & Agribusiness Marketing'* (2022)	• To examine consumers' sensory and neuronal perception of two differing plant-based milks • Can taste nuances be detected in the PFC?	Survey, hedonic sensory taste test, and fNIRS experiment • Taste perception of oat milk vs. almond milk vs. water	• No significant differences of neural activity between two plant-based milk samples • All samples lead to decreased neural activation	• fNIRS as an approach for hedonic taste evaluations • Validation of fNIRS against elements of hedonic taste analysis • fNIRS as valuable tool to study the neural perception of taste with advantages compared to other methodologies • Difficult to measure subtle taste differences with fNIRS
Article 5 (A5): *PACE labels on healthy and unhealthy snack products in a laboratory shopping setting: Perception, visual attention, and product choice* **Authors:** Clara Mehlhose, Daniel Schmitt, Antje Risius **Status:** Published in '*Foods'* (2021)	• To study visual attention of PACE labels on real products in a close-to-realistic shopping environment • To examine consumers' perceptions of PACE labels and their influence on snack choices • To test effectiveness of visual stimuli (PACE labels) for eye-tracking	Survey and mobile eye-tracking experiment • PACE labels on real snack products with varying health values in a laboratory shopping setting	• PACE labels may facilitate more healthy choices, especially for people not yet involved in health behavior • PACE labels might be a meaningful way to combat non-communicable diseases (NCD) and should be followed up on	• Real-world food shopping settings are valuable to study consumer behavior and should be enforced • Mobile ET can be used to study real-world behavior concerning food products

Article 1: "Can neuromarketing add value to the traditional marketing research? An exemplary experiment with functional near-infrared spectroscopy (fNIRS)" examines the feasibility of a mobile fNIRS system. It does so with two exemplary fNIRS experiments dealing with brands and labels, showing that it is possible to measure brand- and label-related PFC activation using fNIRS, and showing that it is possible to use sensory stimuli in a natural environment while also measuring brain activity. It demonstrates that mobile fNIRS embodies an innovative tool to achieve insights into customers' brain activities as it provides significant advantages compared to fMRI. We show that this mainly allows for experiments outside the laboratory, which considerably expands the field of usage of neuroimaging processes and can therefore decrease the costs of neuroimaging. Its potential for neuromarketing and economic research is highly promising. The article further contributes by discussing opportunities and challenges of neuromarketing in general and by pointing out whether and how neuromarketing can add value to traditional marketing research.

Article 2: *"Assessing label frames and emotional primes in the context of animal rearing – Response of an explorative fNIRS study"* follows up on investigating the neural reactions with regard to different connotations (in the sense of framing) of labels and primes (e.g., positive vs. negative representation of image and text content). This was done in the context of food labels for products of animal origin and against the background of raising societal interest for sustainable food and nutrition choices. The article contributes to the development of CN in this area by demonstrating the ability of fNIRS to capture neural processing through labels and primes in the context of agricultural production systems and food contexts, and by showing that the different emotional processing of these perceptional processes is detectable, measurable, and can be made visible with fNIRS.

Article 3: "*Signs of warning: Do health warning messages on sweets affect the neural prefrontal cortex activity?"* examines, against the background of worldwide rising obesity rates, consumers' neural reactions to two graphical health warning messages on sweets. It contributes with its ability to trace the PFC activity back to regions that are associated with reward evaluation and self-control, which can be seen as a first approach to link neural responses to underlying mental processes. The article further validates fNIRS against other elements of socio-empirical research and delivers first explorative insights on what might eventually be possible with fNIRS and what other studies can build on to further validate the fNIRS findings with particular psychological processes and underlying mental states.

Article 4: "*Sensory measurements of taste: Aiming to visualize sensory differences in taste perception by consumers – An experiential fNIRS approach"* contributes to extending the scope of fNIRS as a CN tool, thus transferring the application of fNIRS to the field of sensory science. Combining a hedonic sensory taste test with an fNIRS experiment allowed to investigate the neuronal perception of taste and the extent to which different taste nuances and taste associations were represented in the neural PFC activity. In light of the urgent need to reduce the consumption of animal-based foods to ensure a sustainable food system, consumers' sensory and neuronal perception of two differing plant-based milks were examined. The article shows that fNIRS can be generally used as an approach for hedonic taste evaluations and is a valuable tool to study neural perception of taste. In contrast to other imaging techniques, it has the particular advantage that realistic examination contexts are possible and that the sensory stimuli can be measured with the participants placed in a sitting position. The article provides exploratory insights into what may be possible with the measurement technique fNIRS in the context of sensory research.

Article 5: "PACE labels on healthy and unhealthy snack products in a laboratory shopping setting: Perception, visual attention, and product choice" serves as an approach to come closer to the integration and use of tools that expand the investigation of processes involved in food-related consumer behavior through examining behavior at the place where decisions are made. Against the background that more intuitive food-labelling approaches are one way to increase nutritional awareness in society, the perception of real products in a close-to-realistic environment was assessed with a mobile head-mounted eye-tracker. In a simulated purchase situation, the article examines consumers' visual attention to physical activity calorie equivalent (PACE) labels on 20 different real snack products with varying health values. It contributes by showing that research in close-to-realistic food shopping settings is possible and should be followed up on.

In accordance with the contribution to further develop CN, the dissertation framework is based on the classification of CN tools and used various methodological combinations. It attempts to illustrate the knowledge gained from their application for the further development of CN in the field of food marketing. Figure 3 provides an overview of the framework. It shows that the content-related knowledge gain of the presented studies is higher in those articles where various methodological approaches (e.g., in A4 and A5) were used. Due to the rather explorative research approaches in the first articles (A1 and A2) where one neuroscientific approach was used, these articles focus more on what is theoretically possible with CN and/or fNIRS, report exemplary experiments, and, as such, deliver important first explorative insights on what might, is, or could be possible with mobile CN technologies in this area. In the following, a combination of a neuroscientific approach and a survey was chosen (A3) and could, as such, further validate the neuroscientific methodology against elements of socio-empirical research to connect the imaging findings to particular mental processes. The final step so far was the integration of a CN approach with an additional behavioral measurement (A4: fNIRS and hedonic taste test, A5: ET and purchase simulation) and the use of a quantitative survey, which provided first insights into understanding consumers' information processing and preference evaluations.

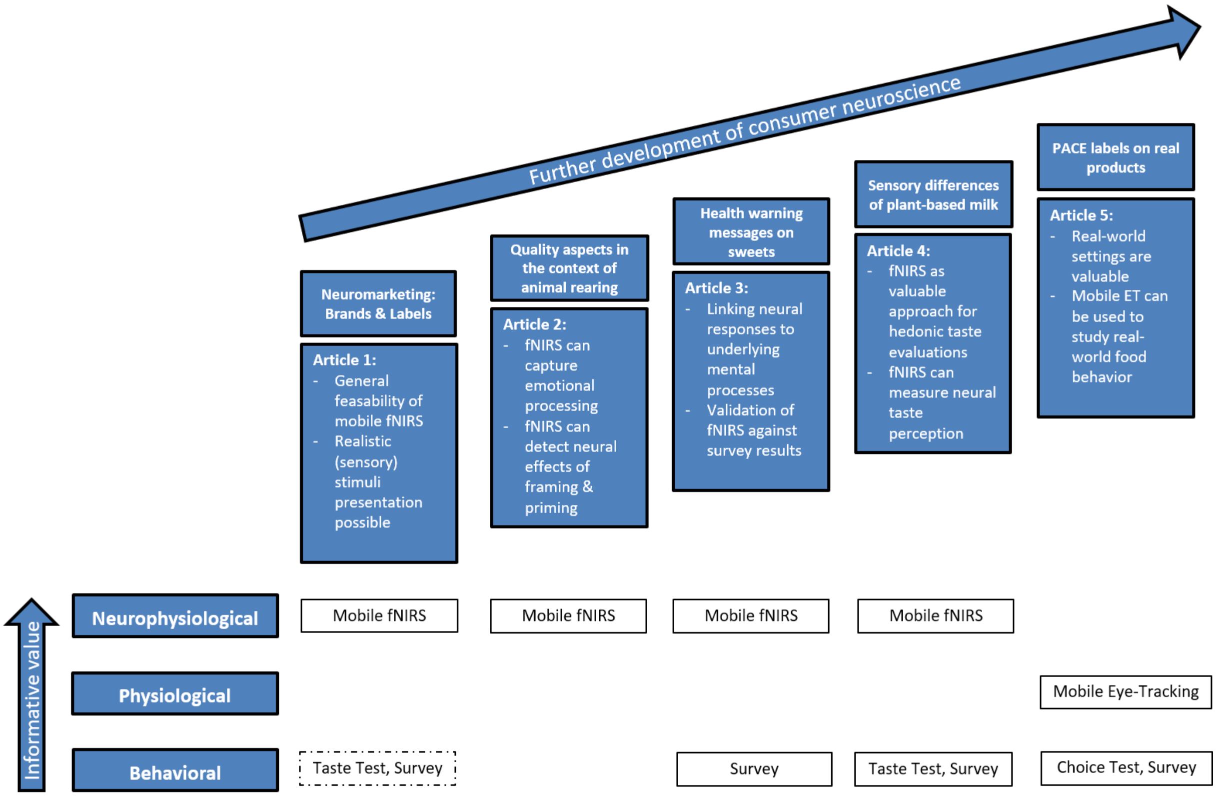

Figure 3: Framework of the dissertation based on a classification of consumer neuroscience tools. Source: Own illustration.

4 Selected Research Articles

Article 1:

Can Neuromarketing Add Value to Traditional Marketing Research? An Exemplary Experiment with Functional Near-Infrared Spectroscopy (fNIRS)

Authors: Stephan Meyerding & Clara Mehlhose

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4.1 Can Neuromarketing Add Value to the Traditional Marketing Research? An Exemplary Experiment with Functional Near-Infrared Spectroscopy (fNIRS)

Highlights

- ► Significant differences in activation of prefrontal cortex between different stimuli
- ► Using mobile functional near-infrared spectroscopy (fNIRS) in Marketing
- ► Higher activation viewing labels and brands compared to non-labeled products
- ► Significantly higher activation when drinking cola compared to just viewing a picture situation
- ► Results indicate the feasibility and high potential of mobile fNIRS

Abstract

Whether neuromarketing methods can add value to marketing research depends on their cost-utility ratio and their ability to offer hidden information that cannot be obtained using other marketing research methods. Due to the limitations of functional magnetic resonance imaging (fMRI) for real-world situations and its high costs, the aim of this study was to examine the feasibility of a mobile functional near-infrared spectroscopy (fNIRS) system. Two experiments dealing with brands and labels are used to discuss how and if neuromarketing can enrich marketing research and to what extent existing limitations and challenges can be overcome.

In both experiments, differences in prefrontal cortex activity were measured. Thus, it is possible to measure brand- and label-related prefrontal cortex activation using fNIRS. As fNIRS is mobile and allows for experiments outside the laboratory, this considerably expands the field of usage of neuroimaging processes and can therefore decrease the costs of neuroimaging.

Keywords: neuromarketing, consumer neuroscience, fNIRS, neuroimaging, attention, brain activity

Introduction

Decoding the 'shopper brain' black box is of great interest for consumer and market researchers, as it promises a better understanding of the underlying brain processes leading to purchase behavior. A new research discipline, also known as neuromarketing or consumer neuroscience, has therefore recently gained more popularity. The use of neuroimaging applications combined with theories and methods from traditional marketing research and related disciplines seeks to study the human behavior related to various marketing stimuli. The aim is to provide data that are not obtainable through common marketing approaches (Lim, 2018). There is rising confidence that, just through supervision of the ongoing neural activities and without the need to ask people directly, neuromarketing might offer hidden data, such as feelings, emotions, values, memories, or even judgments (Lim, 2018; Plassmann, Venkatraman, Huettel, & Yoon, 2015).

To achieve this better understanding of the role emotions and values play in economic decision-making processes, neuromarketing research focuses on the underlying neurophysiological and biological processes (Kopton & Kenning, 2014) that are responsible for our decisions and behavior (Plassmann, Ramsøy, & Milosavljevic, 2012). As a result of this research, it is now well documented that the prefrontal cortex (PFC) is an important part of the brain for sensory evaluations. The PFC is involved in the regulation of decision-making (Heekeren, Marrett, Ruff, Bandettini, & Ungerleider, 2006) and memory work, and is particularly linked to emotional assessments and values (Linder et al., 2010).

Although neuroimaging methods are unlikely to be less cost intensive than supplementary methods in the near future, market researchers see potential in brain imaging and other neuromarketing methods for two main reasons. Firstly, there is the potential that neuroimaging can offer a more efficient trade-off between utility and costs. This potential is based on the expectations that consumers cannot completely communicate their preferences when asked to express them, and that buyers' neuronal activity or other physiological signals contain hidden data about their true preferences (Telpaz, Webb, & Levy, 2015). Such hidden data could probably be used to influence consumers' buying behavior, so the high cost of applying neuromarketing studies would be outweighed by the utility of the improved product design and increased revenues. Initial studies have shown that neuromarketing methods can highlight not only what consumers prefer but also what they will purchase (Çakir, Çakar, Girisken, & Yurdakul, 2018; Kühn, Strelow, & Gallinat, 2016).

The other potential is that neuromarketing offers a precise marketing research approach that can be applied earlier to the design of a product, especially when it comes to the use of brands and labels. The hypothesis is that neuromarketing information provides a more accurate indication of the underlying preferences than information from conventional market research experiments, and will remain insensitive to the biases that are often problematic in subjective methods of valuation. Product concepts with different characteristic specifications can be evaluated rapidly, and those concepts that are not satisfactory can be eliminated at an early stage in the product development process. This application of neuromarketing would allow more efficient allocation of resources to develop more promising product concepts (Ariely & Berns, 2010; Çakir et al., 2018). Several studies have established already that neural activities can be used to identify preferred brands (Chen, Nelson, & Hsu, 2015), brand choices (Plassmann et al., 2012), or value experiences of brands (Fehse, Simmank, Gutyrchik, Sztrókay-Gaul, & Briesemeister, 2017; Reimann, Castaño, Zaichkowsky, & Bechara, 2012) and labels (Linder et al., 2010). But although product packaging and design is one of the closest contact points between a consumer and a brand, there is surprisingly little neuromarketing research on this to date. Considering the benefit promise and additional value of neuroimaging applications, remarkably few studies have produced empirical findings (Krampe, Strelow, Haas, & Kenning, 2018; Lee, Chamberlain, & Brandes, 2018; Lim, 2018).

One main reason might be that the majority of these results were generated using functional magnetic resonance imaging (fMRI), the most popular and commonly used neuroimaging technology (Lee et al., 2018). The advantages of fMRI, such as the high and very detailed spatial resolution, are offset by some serious disadvantages, especially when it comes to the investigation of real-world behavior. It is questionable whether observations of the neural activity generated while the participant is lying still and immobile in a tight and high-noise scanner environment and exposed to unrealistic stimuli can really hold true (Spence, 2016).

We therefore see great potential in an innovative neuroimaging method: functional near-infrared spectroscopy (fNIRS). fNIRS is a non-invasive optical imaging technique that creates a map of the blood oxygenation in local brain areas during neural activity through examining the cerebral blood flow (CBF) (Jackson & Kennedy, 2013). Brain activation measurement with fNIRS seems to have great potential as it reduces some critical limitations of the fMRI. It is mobile and lower in cost, enabling use in real-world situations for freely moving subjects (Ferrari & Quaresima, 2012; Kopton & Kenning, 2014; Piper et al., 2014; Scholkmann et al., 2014). As it is comfortable and tolerant to body movement, it is highly portable, and is described as a major innovation in neuroeconomic research (Pinti et al., 2018).

Despite the novelty of fNIRS in neuroscience, the reliability and validity of the method to measure cortical activation have been shown in a wide spectrum of studies inside and outside the laboratory. Studies trying to focus on more realistic and natural environments have used fNIRS—for example, while walking in a city (Pinti et al., 2015), driving a car (Yoshino, Oka, Yamamoto, Takahashi, & Kato, 2013), flying an airplane simulator (Verdière, Roy, & Dehais, 2018), playing table tennis and piano (Balardin et al., 2017) or focusing on a realistic grocery shopping atmosphere (Krampe et al., 2018).

But whether neuromarketing and technologies like fNIRS can really play a successful part in marketing research depends on three essential questions. Firstly, can neuromarketing disclose unknown data that are not present in supplementary techniques? Secondly, can it offer a more efficient cost-utility trade-off than supplementary conventional marketing research methods? Thirdly, can it provide neuromarketing studies with early useful data about a product’s design or characteristic specifications (Ariely & Berns, 2010)?

Our contribution is therefore to diminish the problem described by Lee et al. (2018), that there is a lack of discussion on whether neuroscience and neuroimaging applications are really useful and worth pursuing as approaches for traditional marketing research. This study further promotes the use of fNIRS, resulting in a decrease in the cost and an increase in the usability of neuroimaging, and therefore helps neuromarketing to add value to marketing research. Furthermore, we support Lee et al.’s (2018) proposal to extend the range of methods used and therefore demonstrate with two small fNIRS experiments the possibilities this new method offers for neuromarketing. With few articles using fNIRS in the brand and package design context, we examine the feasibility of a mobile fNIRS system for neuromarketing research in a food-related context. Therefore, our two experiments deal with the different influences of strong and weak brands’ respective labels in a food-related context.

The first experiment examines the influence of the organic and the regional food label on prefrontal cortex activity. A well-known food label in Germany is the German organic label, Bio-Siegel (Meyerding, 2016; von Meyer-Höfer, von der Wense, & Spiller, 2015), as organic food is becoming more and more popular due to the society’s health and environmental concerns (Pearson, Henryks, & Jones, 2010); therefore, it has been used in this study as food label information. The same pictures were then labeled with the German label for the local origin of products (Regionalfenster), as regionalism of products has also become important for consumers over the last few years (Newman, Turri, Howlett, & Stokes, 2014). The hypothesis is that the organic and the regional food labels on the different products lead to increased activity in the PFC area compared to the same products without any label.

The second experiment executes a simple taste test with strong and weak cola brands, looking at their effect on PFC activity. Coca-Cola and Pepsi were chosen as strong cola brands, versus Vita Cola and Topstar as weak cola brands. In simple taste tests, the subjects were told to consume a small amount of the four cola beverages after they were shown the respective labels. It is hypothesized that there is a difference in PFC activation while drinking cola of a strong brand versus a weak one, although the subjects received the same cola drink in every test. Various fMRI studies have shown that strong brands and labels lead to increased PFC activity (Fehse et al., 2017; Linder et al., 2010). The main question in the experiment was whether this can also be measured using a mobile fNIRS system.

Against the background of the few empirical findings produced in the food-related neuromarketing context, with the simultaneous increasing hope of decoding the ‘shopper brain’ black box, there is an urgent need to discuss the sense and nonsense of using neuroimaging technologies in marketing research. Can it really add value to the traditional marketing research? To the best of our knowledge, there is no other neuromarketing study which also realistically highlights the difficulties of experiments in naturalistic environmental settings. The article closes with an additional discussion about the challenges of neuromarketing and with a view on whether neuromarketing can really add value to the traditional marketing research.

Methods

The present research used a mobile fNIRS system to observe PFC activity during food label and taste tests. Two different experiments were conceptualized. The first involved eight food pictures, each labeled differently three times, from which the subjects had to decide the one they would most likely purchase. The second experiment included pictures of four different cola brands and the cola drink, which the subjects had to taste five times before deciding which one they preferred. The following section describes the fNIRS measurement first. After this, the sample is characterized. Finally, the procedure of the two experiments, the experimental design, and the means of data processing are specified.

Functional Near-Infrared Spectroscopy Measurement

The underlying biological process of fNIRS and fMRI measurement is called neurovascular coupling. In this process, brain activity increases oxygen consumption, accompanied by increased cerebral blood flow (CBF) in activated areas of the brain (Jackson & Kennedy, 2013;

Wolf et al., 2002). This hemodynamic response leads to a strong increase in oxyhemoglobin and a decrease in deoxyhemoglobin in these areas. As a result of this, an excess of oxyhemoglobin can be measured in the venules, which normally show a higher concentration of deoxyhemoglobin. In fMRI, this is described as the BOLD effect (blood oxygen level dependency), through which, four to six seconds after being exposed to a stimulus, the neuronal activities can be expressed. It is the change of oxygen saturation through the change of the CBF that can be made visible and allows the drawing of conclusions about cortical hemodynamic processes in the brain. Several studies have shown that the signal measured in fNIRS correlates with the fMRI BOLD signal, even if this BOLD effect in fMRI is measured through the paramagnetic differences between oxy- and deoxyhemoglobin, while in fNIRS, the BOLD-like effect is based on the intrinsic optical absorption of blood flows (Masataka, Perlovsky, & Hiraki, 2015). Due to the process of neurovascular coupling, it is possible to compare the results of fMRI to those of fNIRS studies (Aasted et al., 2015), as the time course in fNIRS can be analyzed equivalently to that of the fMRI BOLD signals (Cui, Bray, Bryant, Glover, & Reiss, 2011; Köchel et al., 2011).

In 1977, Jobsis was the first to use near-infrared light to make oxygen saturation changes of tissue visible; in 1985, Ferrari and colleagues pioneered using the method for cerebral oxygenation, so the development of fNIRS measurement is clearly still at its beginning (Ferrari, Giannini, Sideri, & Zanette, 1985; Jobsis, 1977). Nowadays, near-infrared light with wavelengths between 650 nm and 950 nm is used (Ferrari & Quaresima, 2012; Scholkmann et al., 2014). The light sources are placed directly on the forehead and send the light in a u-shaped form to the light detectors. The light thereby passes through the skin of the forehead and is mainly absorbed by oxy- and deoxyhemoglobin in the brain. As the light has to pass through the skin twice, it is diffusely scattered, and so blood hemoglobin concentration changes are made visible (Tak & Ye, 2014).

To execute an optical measurement of the CBF, a mobile continuous-wave fNIRS system (NIRSport; NIRx Medical Technologies, Berlin, Germany) is used in this study. The optical signals were measured on two wavelengths, 760 nm and 850nm, and were collected at a sampling rate of 62.5 Hz. The neoprene headband used consisted of eight near-infrared light sources (diodes) and seven detectors (optodes), placed in a u-shaped form directly on the participant’s forehead at a distance of 3cm from each other. The topographical layout for the PFC is shown in Figure 1.

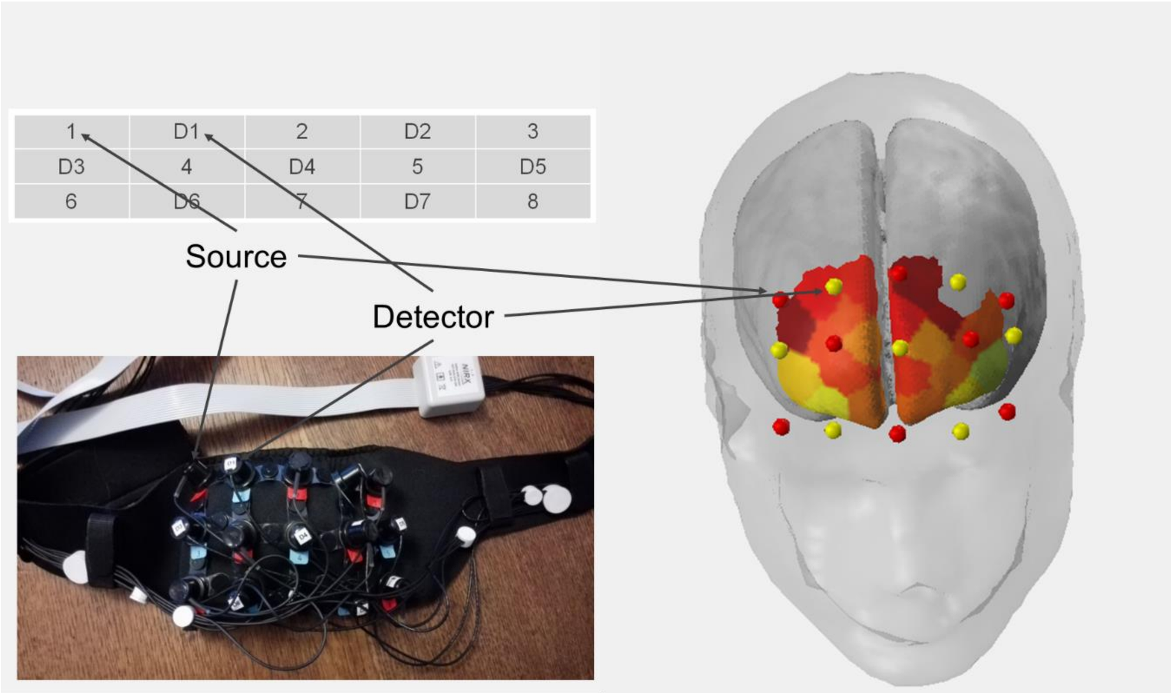


Figure 1: Topographical layout for prefrontal cortex measurement.

To set up the experimental design, NIRStim 4.0 software was used. For data acquisition, we used NIRStar (version 14.2). It was decided to combine the software as information about the experimental design is automatically sent from NIRStim to NIRStar. Data pre-processing—in terms of controlling the raw data, low- and high-pass filtering, correcting motion artifacts, computing hemodynamic states, and the following statistical analysis—were performed using nirsLAB (version 2017.6).

Participants

Thirty-one subjects participated in the two experiments. All were students of the Georg-August-Universität in Göttingen, Germany. Ages ranged between 20 and 27 years; 18 were female, the other 13 male. All indicated that they were in possession of normal or near-normal visual ability. The subjects provided verbal informed consent about participation after the experimental procedure was explained to them. The experiment took part between 28 May and 6 June 2017, and the subjects participated without financial compensation.

In contrast to fMRI measurements, there are no exclusion criteria for the participants, as it is a non-invasive measurement method, where blood oxygenation concentration changes are made visible using near-infrared light, which is harmless and without side effects. Furthermore, it is less expensive and less time-consuming than fMRI measurement, so we had a comparatively large number of test subjects in our experiments.

Experimental Procedure

Before beginning the experiments, the subjects were given detailed instructions about the procedure. As none of them had taken part in any neuroscience experiment before, the function of the headband especially had to be explained carefully to prevent negative emotions, which could in turn cause distortive hemodynamic responses (Silvers, Wager, Weber, & Ochsner, 2015). The subjects were informed that the experiment would consist of two different parts. Within the first, eight different food products were shown one by one in random order.

A total of 24 food pictures had to be viewed, as all eight products were shown in three modifications concerning the labeling: one labeled with the organic label, one with the regional label, and one without any label information (Figure 2).

Figure 2: Example of the food picture modifications through labels.

Note: Each of the eight food pictures was labeled differently three times: once with the organic label, once without label information, and once with the regional label. The subjects had to decide which version of the product they would purchase.

The subjects were asked to view them all carefully and then to make a decision as to which version of the respective eight products they would prefer to purchase.

The second part of the experiment consisted of a simple taste test with four different cola beverages (Figure 3).

Figure 3: The four different cola beverages.

Note: These pictures of the cola beverages Coca-Cola, Pepsi, Vita Cola, and Topstar were shown to the subjects followed by the instruction to take a sip of the respectively labeled mug in front of them. All mugs contained the same cola beverage from a German discounter.

The subjects were asked to drink a small amount after they had seen the label of the respective cola brand. They had to drink each of the four colas five times in random order and afterwards rank the taste of every cola from 1 = "I don't like it at all" to 8 = "It is delicious." What the subjects did not know was that all mugs contained the same cola from a German discounter, despite their respective labeling.

For the experiment procedure, each subject was placed in a chair in front of a screen that was used to show the different stimuli. As all of them were right-handed, the four differently labeled mugs with the cola beverage inside were placed directly on the right side of the screen. They were placed at such a distance from the participant that they could be reached easily with one hand and without major body and head movements, to avoid strong movement artifacts (Tachtsidis & Scholkmann, 2016).

Experimental Design

To avoid confusion for the subjects, the experimental procedure was presented to them as one experiment with two different parts, but actually two experiments were set up. The first was the food label experiment, the second the cola taste test. The two experiments consisted overall of 11 different conditions (C) that were presented in a block design. Conditions C1.1–C1.3 were part of the food label experiment. In the first experiment, eight different food stimuli were presented: apples, eggs, strawberries, meat, milk, carrots, salami, and tomatoes. These products were chosen as they can all be purchased in a normal supermarket and because they are usually available in any one of three conditions: organic, regional, or non-labeled.

Conditions C1.1, C1.2, and C1.3 represented respectively the organically labeled, the non-labeled, and the regionally labeled modification of these eight products. Each picture was shown only once, the stimulus repetition being measured through the three different label modifications of the products. This means every label was shown eight times, but each time on a different product (Figure 4).

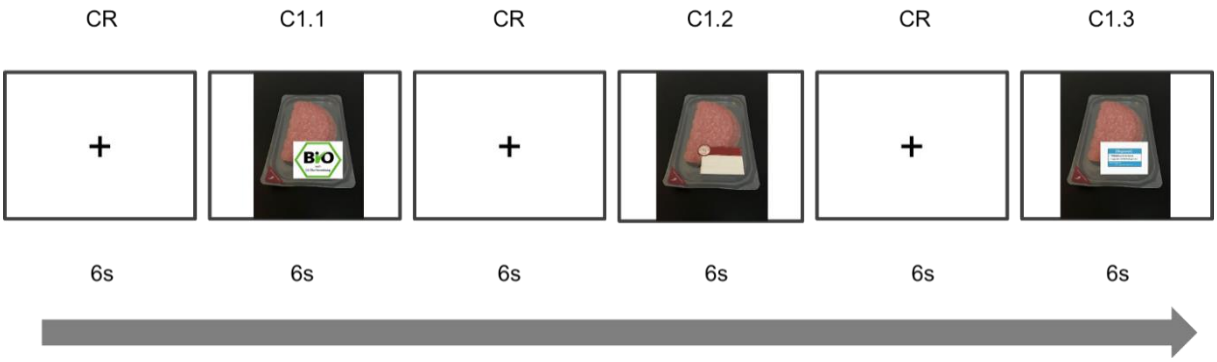


Figure 4: Experimental design of the food label experiment with salami as product example.

Note: C1.1 is the product with the organic label, C1.2 the product without label information, and C1.3 the product with the regional label. The pictures and the cross (CR = break) were each shown for six seconds. The three conditions C1.1–C1.3 are one block. As there were eight different food product pictures, this block was repeated eight times, one time for each product.

Conditions C2.1–C2.4 and C2.5–C2.8 were part of the cola taste test. Conditions C2.1, C2.2, C2.3, and C2.4 represented the pictures of the cola cans: Pepsi, Coca-Cola, Vita Cola, and Topstar. They were each followed by the instruction to take a sip (Jetzt trinken!) in conditions C2.5, C2.6, C2.7, and C2.8 (Figure 5).

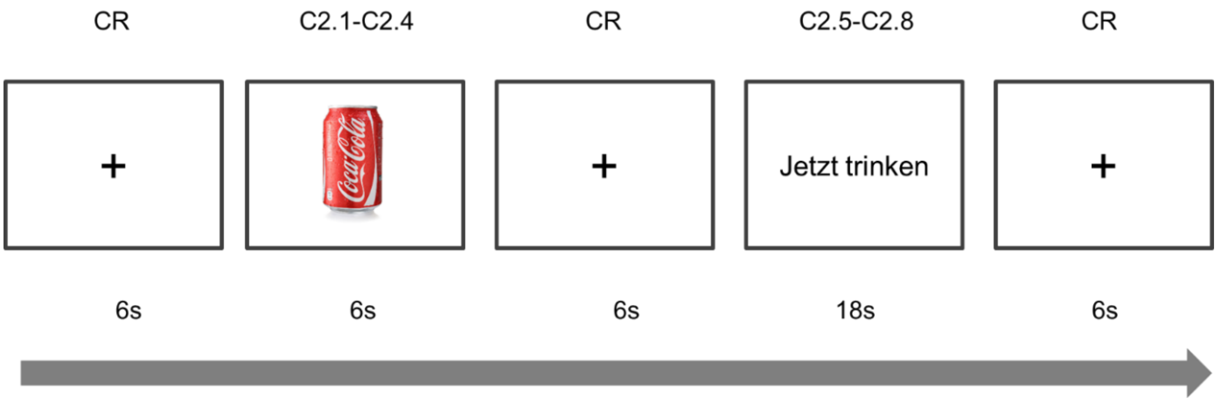


Figure 5: Experimental design of the cola taste test with Coca-Cola as cola beverage example.

Note: In this second experiment, one block consisted of the cola can picture, followed by the instruction "Jetzt trinken", to take a sip of the respectively labeled mug. C2.1–C2.4 are the cola can pictures (C2.1 = Pepsi, C2.2 = Coca-Cola, C2.3 = Vita Cola, C2.4 = Topstar). They were each followed by the respective instruction to drink in the conditions C2.5–C2.8. Coca-Cola (C2.2) is here chosen as the example. The design for the three other cola drinks was identical. Each block was repeated five times for each cola beverage.

All pictures and all instructions were followed by a break (CR). The subjects saw a cross: it was explained to them as a little break to set their neural activity back to the baseline.

All pictures of both experiments (C1.1–C2.4) and the break (CR) were shown for six seconds, while the welcome instruction lasted 18 seconds. The instructions to take a sip of the respective cola beverages (C2.5–C2.8) were shown for 18 seconds, during which time the participants had to taste the cola beverages. In contrast to the first experiment, where every picture was shown only once and one block contained the three labels, in the second experiment every block of one beverage was repeated five times. Therefore, overall, the subjects had to take 20 sips of cola beverages. The task duration for the pictures was chosen because the BOLD effect follows approximately four seconds after the neuronal activity (Xu, Graber, & Barbour, 2017). For the instructions and the drinking task, the time was adjusted to the task. To avoid Mayer waves (Tak & Ye, 2014), which are transient hemodynamic perturbations with a characteristic frequency of 0.1 Hz (= 10 seconds), the times were not defined as multiples of 10 seconds (Julien, 2006). The total duration of the experiment for each subject was a little over 21 minutes (1,267 seconds).

In the first experiment, the order of the products was identical for every participant, but within the food product, the organic, no label, and regional products were shown in a randomized order. In the second experiment, the order of the colas was randomized. They were also randomized in every one of the five repetitions. However, in every case a cola picture was shown, the participant had to drink the cola afterwards.

After the experiments were finished, the subjects were asked to fill out a short questionnaire to gather information about their purchasing behavior concerning organically and regionally produced goods, their frequency of drinking cola, and the pleasantness ratings of the cola taste tests. First of all, the questionnaire showed the respective three modifications of the eight food stimuli again, from which the preferred one had to be marked with a cross. Afterwards, the participants stated how often they drink cola and how often they buy regionally and organically produced goods, ranging from “never” to “several times a day”. Then, the labels of the four different colas were shown again, and their taste had to be ranked on an eight-point scale: 1 = “I don’t like it at all” to 8 = “It is delicious”.

Data Processing

Before recording data, the experimental design had to be loaded in NIRStim to show the stimuli to the subjects. After preparing them with the headband, it is necessary to calibrate the detector gains in NIRStar for each subject to optimize the signal-to-noise ratio. The signal quality of the channels has to be checked before recording, and the topographical layout is set up here. While the stimuli are presented to the subjects using NIRStim, it simultaneously transfers information about the conditions to the recording software NIRStar. After the experiments, the data were loaded into the analysis software nirsLAB. There, the different conditions were marked and their duration defined in detail. The distance of the first channel, describing the distance between source and detector, was set to 3 cm to enable optimal scattering of the light (Jackson & Kennedy, 2013). To ensure high and consistent data quality, the raw data were checked and bad channels excluded. Bad channels are defined by nirsLAB as channels with a coefficient of variation of > 15% and a gain setting of < 8. The signal-to-noise ratio has a tendency to decrease with increasing gain value. Bad channels had to be excluded from the analysis in only two cases. This highlights the importance of checking the signal quality of all channels before recording. To convert the absorption of the near-infrared light into oxy- and deoxyhemoglobin concentration, the modified Beer-Lambert law algorithm was used, being the most commonly accepted (Jackson & Kennedy, 2013; Scholkmann et al., 2014). Afterwards, high- and low-frequency filtering was applied to remove fluctuations unrelated to the experimental paradigm (Xu et al., 2017). In order to compute the hemodynamic state, it was necessary to set the parameters first. For these hemoglobin values, the Gratzer spectrum[1] was used. After computing hemodynamic states, the quality of the channel from each subject was checked again by plotting time series data and mapping the hemodynamic states.

In the first step of data analysis, the data for each subject were processed by statistical parametric mapping (SPM Level 1). Only oxyhemoglobin data were used, having been shown to correlate more with cerebral blood volume and with a higher signal-to-noise-ratio (Hoshi, Kobayashi, & Tamura, 2001). The basis function was modified through the hemodynamic response function (hrf-specification) (Xu et al., 2017). After estimating the general linear model coefficients, the significant single subject SPM results of the neural activity in the PFC were compared among the different conditions. A one-sided t-test was used to measure the differences between the conditions. As oxyhemoglobin data were used, only channels showing significantly positive t-statistic values were included in the results when calculating the share

[1] Compiled by Scott Prahl using data from W. B. Gratzer, Med. Res. Council Labs, Holly Hill, London, and N. Kollias Laboratories, Harvard Medical School, Boston, MA.

of participants with a higher neuronal activation of the PFC in one condition compared to another condition. The t-test was done for each comparison between conditions for each measurement location (source-detector combination). The significance level was set at 10% (p-value = 0.1). The individual contrast images were used for a second-level analysis to measure significant differences in neural activity between all subjects within the group; therefore, statistical parametric mapping (SPM Level 2) was performed again over all subjects. To compare the number of activated channels and their intensity, the minimum value for each brain image was set at -10 and the maximum value at +10. In the color code of nirsLAB, red means a positive t-value and therefore a strong activation.

Results

Attempting to explain the impact of brands and food labels on PFC activity, two different experiments were set up, both dealing with the different influence of strong vs. weak brands and labels in a food-related context. In this section, the SPM Level 1 results of both experiments are presented. First, there will be a general description of the questionnaire results to achieve a better understanding of the participating subjects; then, the results of the food label choices will be presented, followed by a description of the cola taste test.

Survey Results

After completing the fNIRS measurement, all of the participants were asked to fill out a short questionnaire to gather information about their purchasing behavior concerning organically and regionally produced goods, their frequency of drinking cola, and the pleasantness ratings of the cola taste tests, yielding the following results.

The subjects purchase and consume organic products, on average, one to two times a week. On average, the participants purchase and consume regional products three to four times a week.

However, there are some differences concerning the products. As can be seen in Figure 6, more than half of the subjects would choose the organic salami and the organic meat. In contrast, organic production of strawberries, tomatoes, and carrots seems to be of less importance.

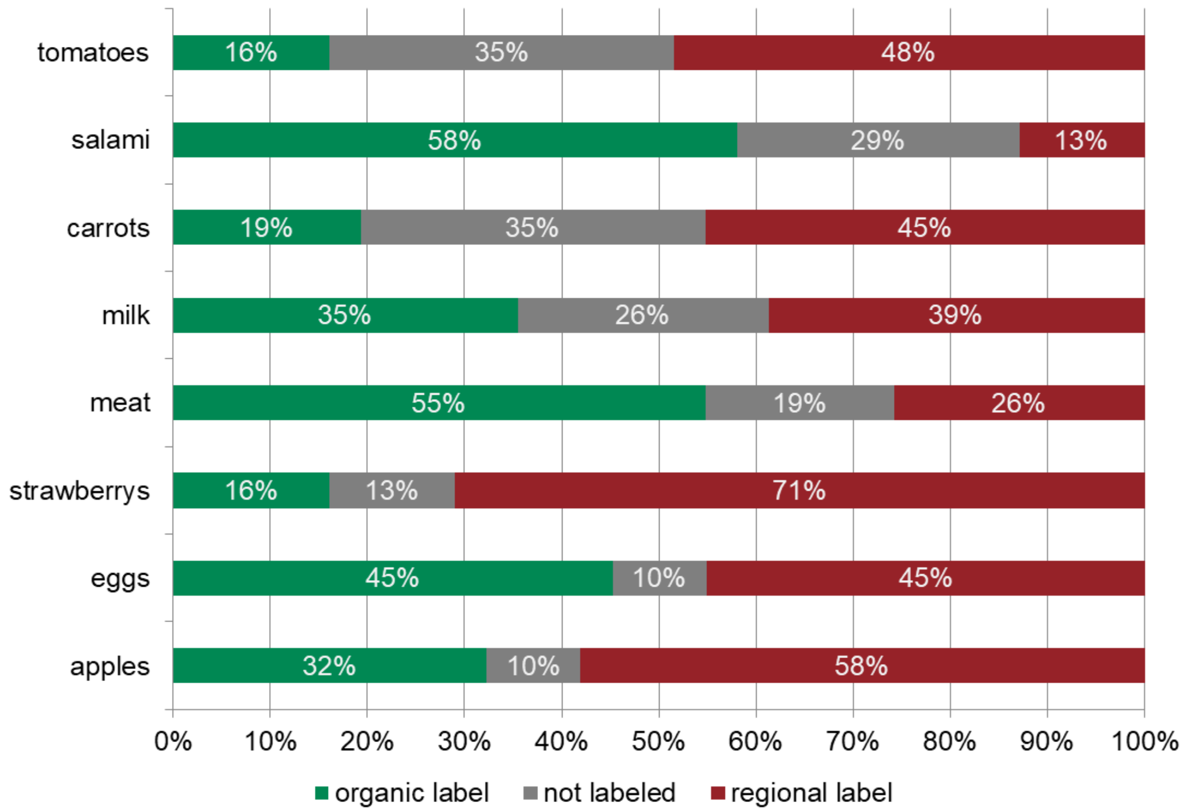


Figure 6: Label preferences for the eight different food pictures.

Note: The subjects had to decide which label variation of the eight presented products they would purchase.

A food label seems to be important, because the non-labeled option for these products was not preferred by a majority of subjects. Concerning the tastiness of the colas in general, the subjects rated Pepsi the highest. The results, based on the subjects' highest and lowest pleasantness rating for the different colas, can be seen in Figure 7. The well-known cola brands Coca-Cola and Pepsi received the highest ratings.

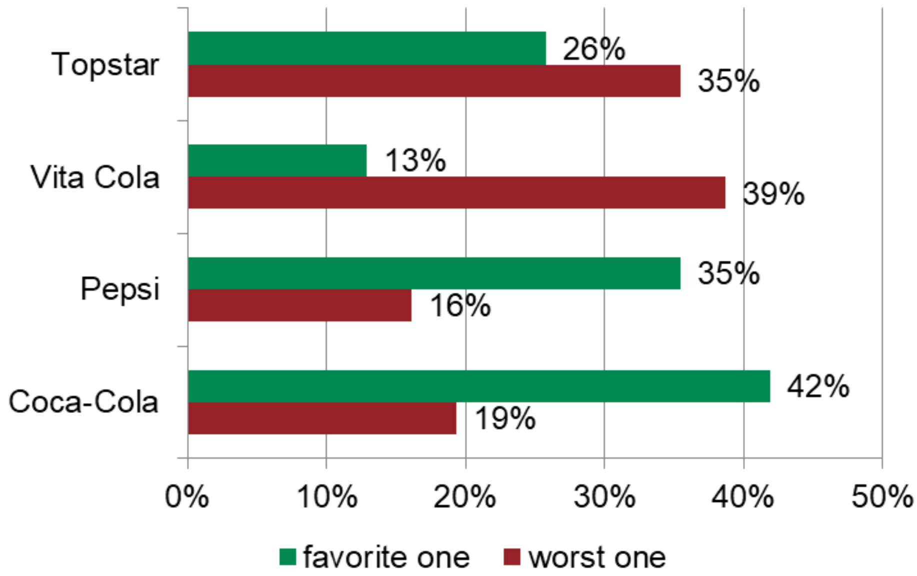


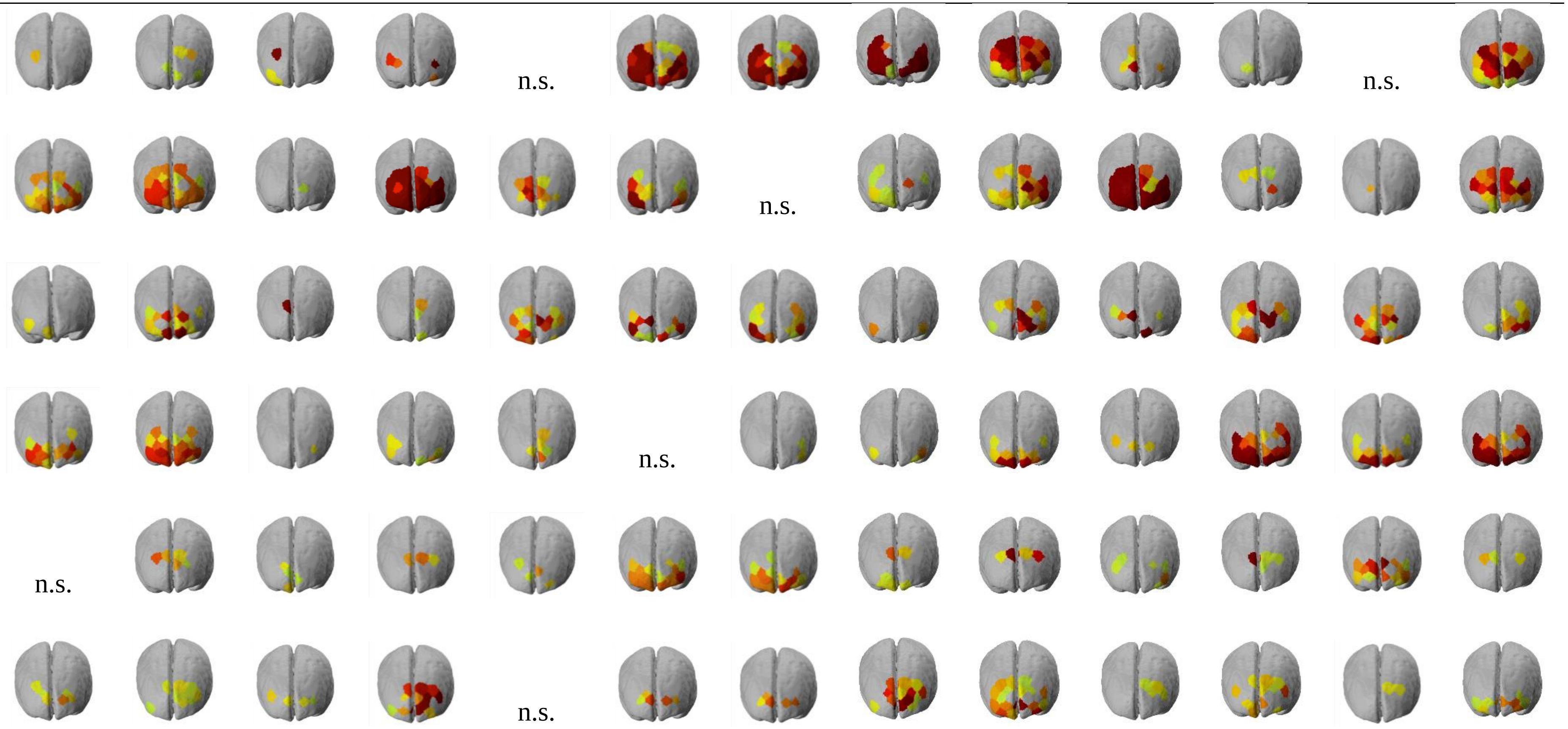
Figure 7: Pleasantness ratings of the cola brands based on the highest/lowest ranking the subjects gave.

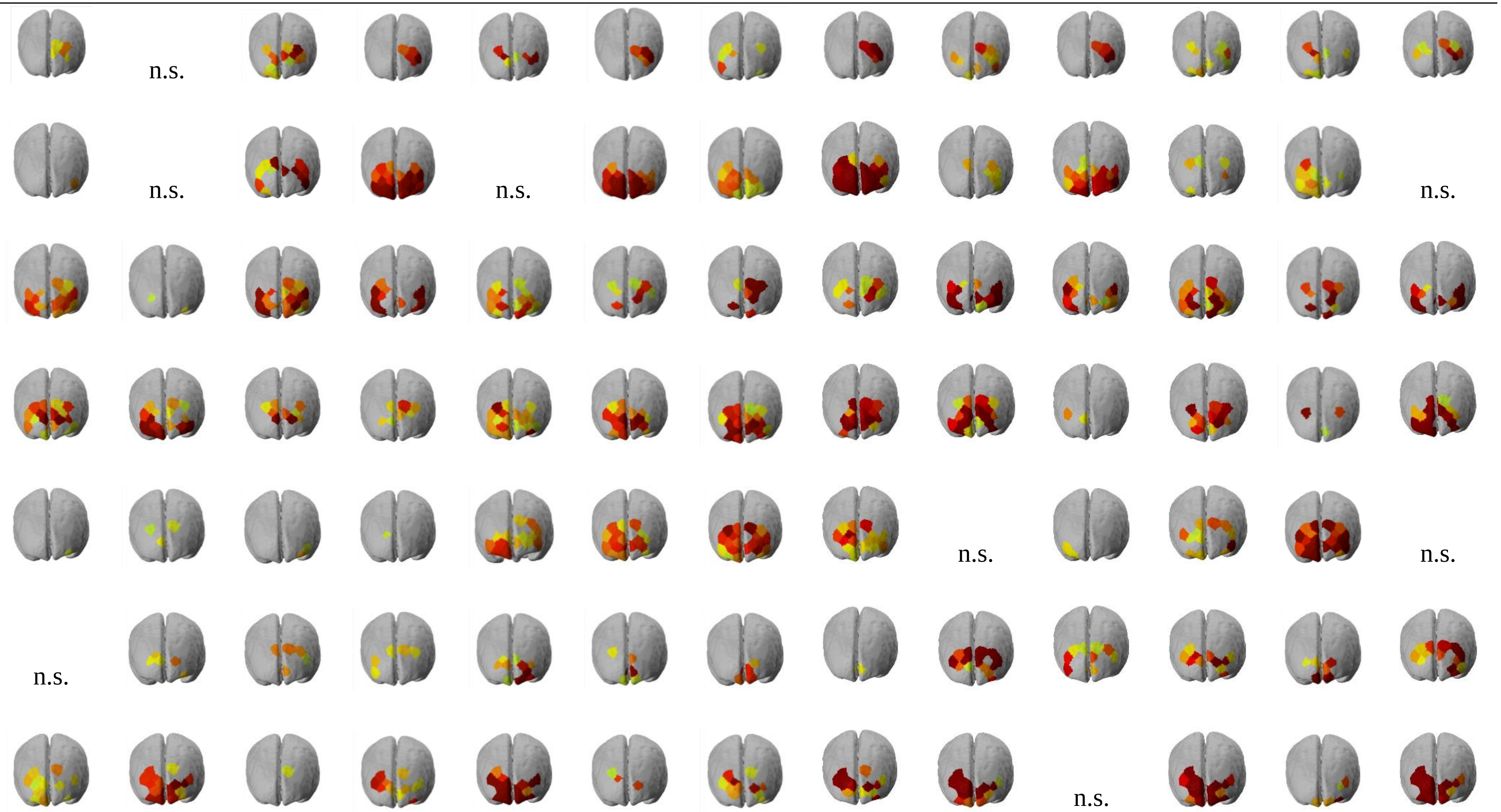
Food Label Experiment

The aim for this first experiment was to show that both the organic and the regional label leads to an increase of activity in the prefrontal cortex, compared to the same product without any label or information about the method of production. To answer this question, statistical parametric mapping at the individual level (SPM Level 1) was performed with respect to the conditions C1.1–C1.3 (C1.1 = organic label, C1.2 = no label information, C1.3 = regional label). A t-test was used to measure the differences between the conditions; the significance level was set at 10% (p-value = 0.1). Table 1 shows the results of the comparative analysis for all compared conditions.

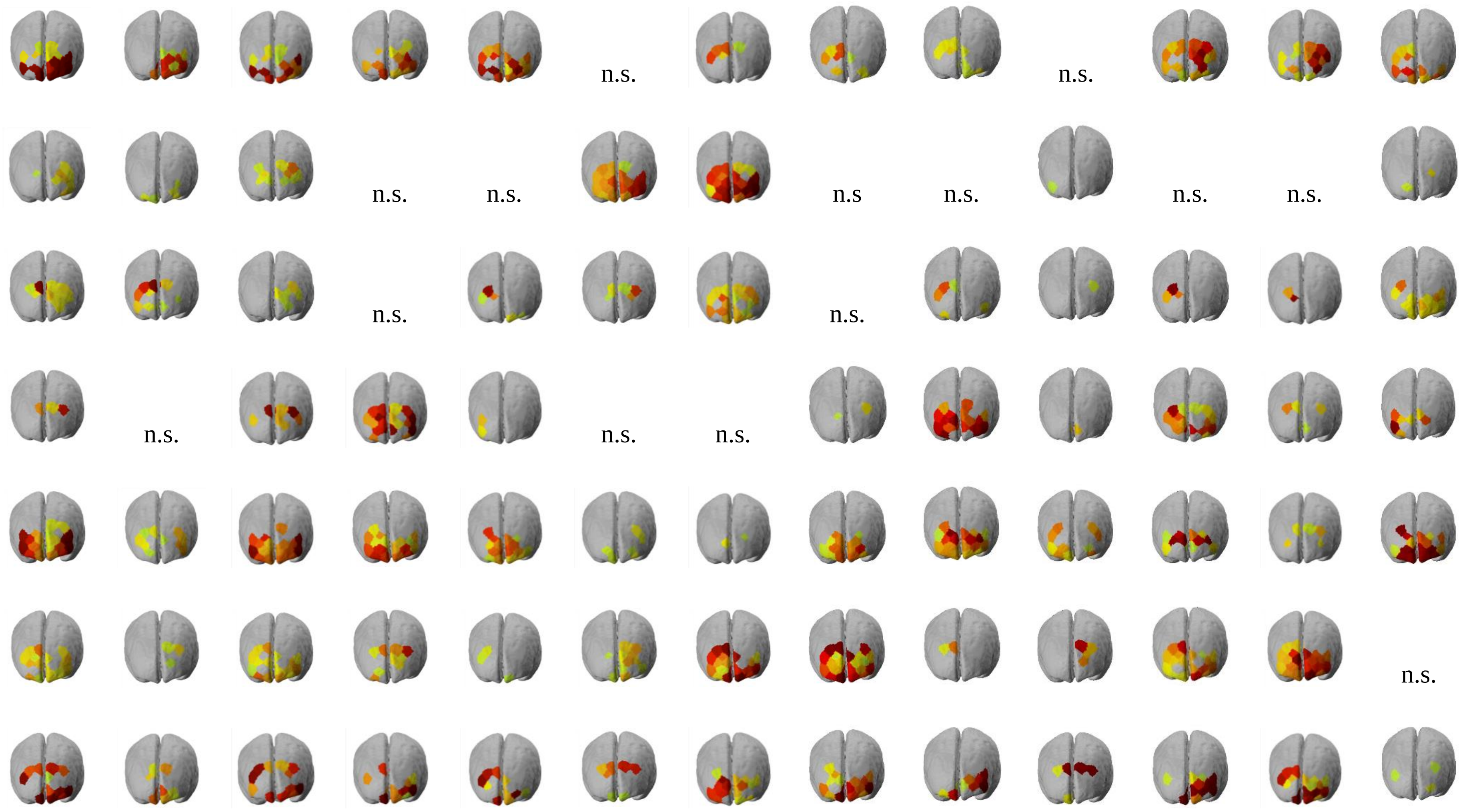
Table 1. Threshold SPMt Level 1 (Hboxy) results between different conditions

	C1.1 > C1.2	C1.3 > C1.2	C1.1 > C1.3	C2.1 > C2.4	C2.5 > C2.8	C2.2 > C2.3	C2.2 > C2.1	C2.2 > C2.4	C2.6 > C2.7	C2.1 > C2.3	C2.5 > C2.7	C2.5 > C2.6	C2.6 > C2.8
1					n.s.							n.s.	
2							n.s.						
3													
4						n.s.							
5	n.s.												
6					n.s.								

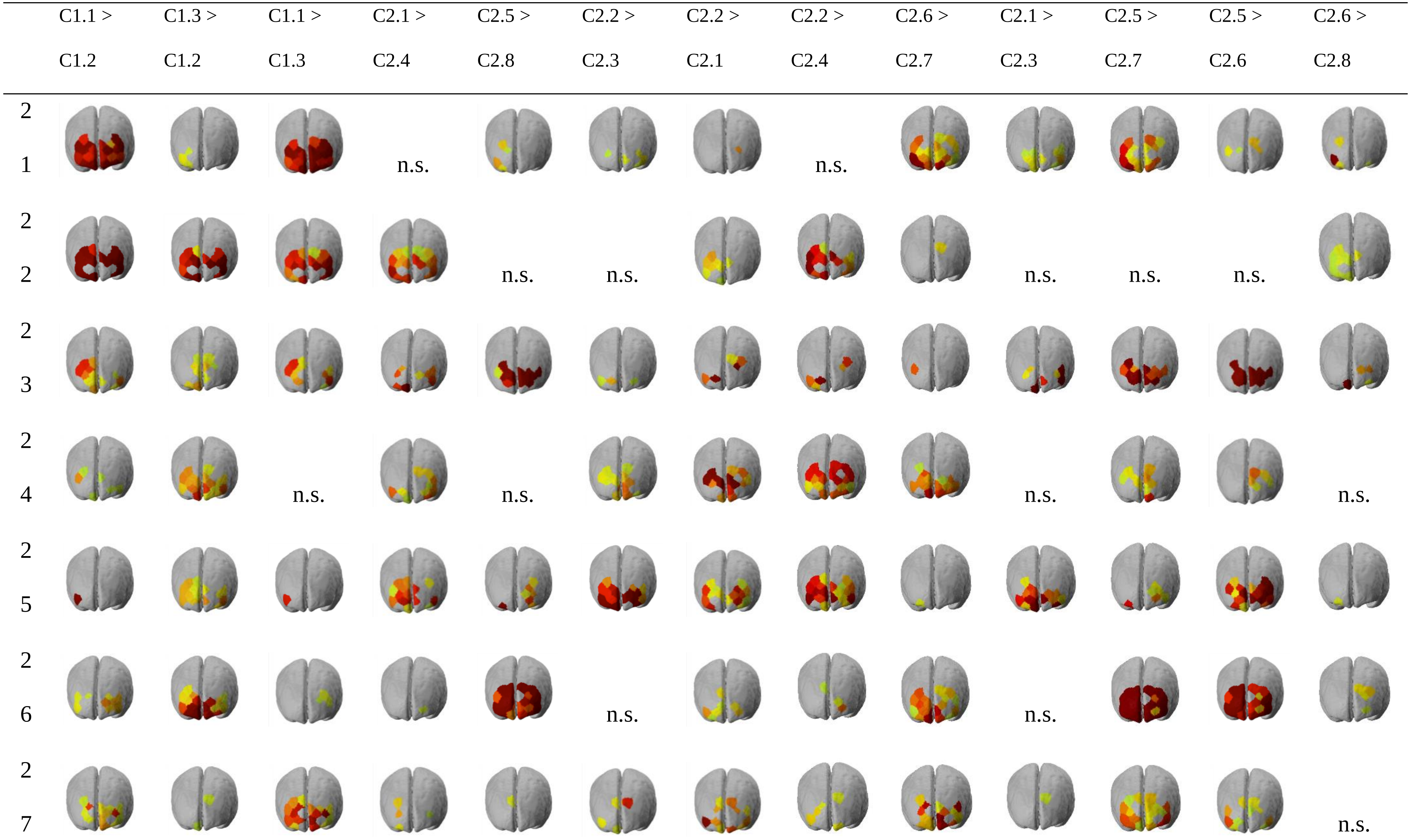




	C1.1 > C1.2	C1.3 > C1.2	C1.1 > C1.3	C2.1 > C2.4	C2.5 > C2.8	C2.2 > C2.3	C2.2 > C2.1	C2.2 > C2.4	C2.6 > C2.7	C2.1 > C2.3	C2.5 > C2.7	C2.5 > C2.6	C2.6 > C2.8
7		n.s.											
8		n.s.			n.s.								n.s.
9													
10													
11									n.s.				n.s.
12	n.s.												
13										n.s.			



	C1.1 > C1.2	C1.3 > C1.2	C1.1 > C1.3	C2.1 > C2.4	C2.5 > C2.8	C2.2 > C2.3	C2.2 > C2.1	C2.2 > C2.4	C2.6 > C2.7	C2.1 > C2.3	C2.5 > C2.7	C2.5 > C2.6	C2.6 > C2.8
14						n.s.				n.s.			
15				n.s.	n.s.			n.s	n.s.		n.s.	n.s.	
16				n.s.				n.s.					
17		n.s.				n.s.	n.s.						
18													
19													n.s.
20													


C1.1 > C1.2
C1.3 > C1.2
C1.1 > C1.3
C2.1 > C2.4
C2.5 > C2.8
C2.2 > C2.3
C2.2 > C2.1
C2.2 > C2.4
C2.6 > C2.7
C2.1 > C2.3
C2.5 > C2.7
C2.5 > C2.6
C2.6 > C2.8
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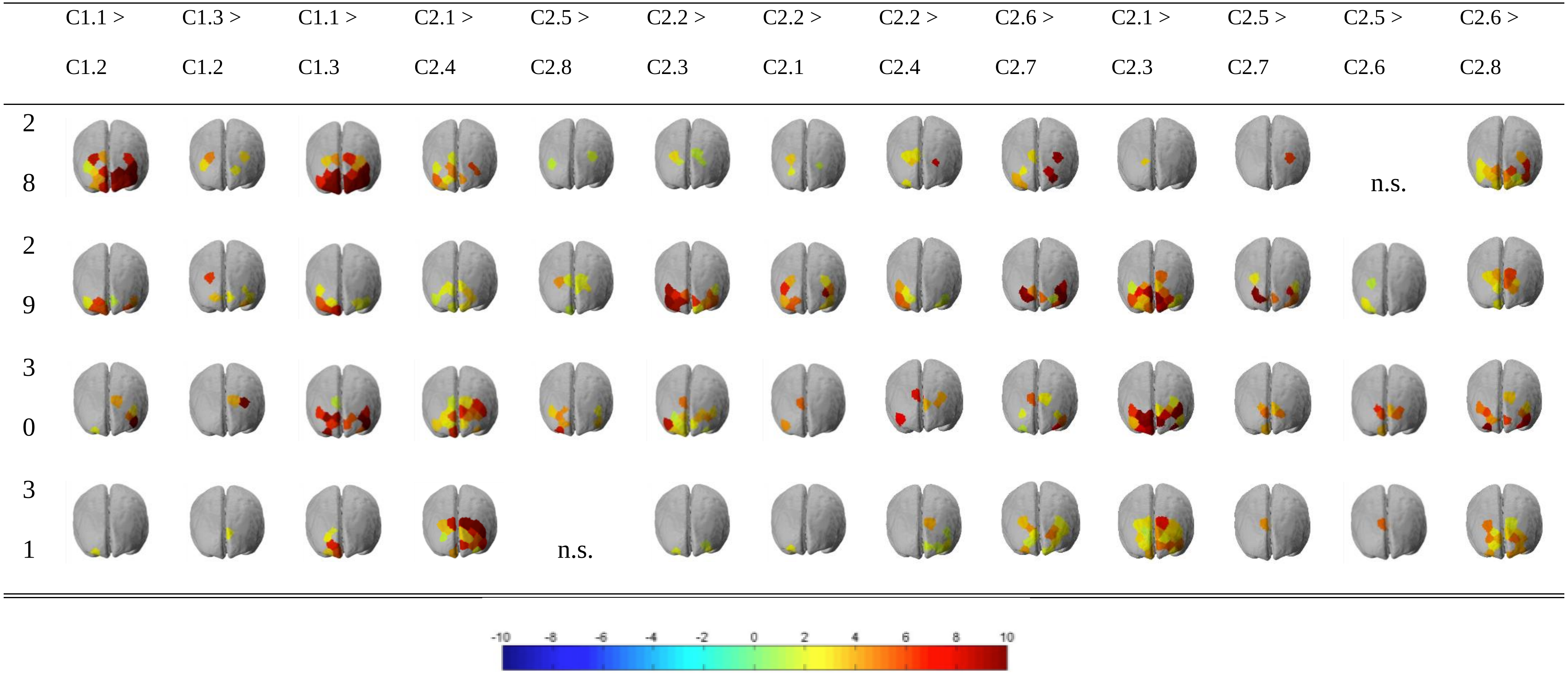

Notes. Significant at the 0.10 level. n.s. = no significant difference in neural activation could be measured for this condition. Each row is one participant and one column is one condition comparison. The differently activated brain areas of one participant over the different conditions can be seen. The comparisons of the conditions C1.1 > C1.2, C1.3 > C1.2, and C1.1 > C1.3 are part of the food label experiment. The conditions C2.1 > C2.4, C2.5 > C2.8, C2.2 > C2.3, C2.2 > C2.1, C2.2 > C2.4, C2.6 > C2.7, C2.1 > C2.3, C2.5 > C2.7, C2.5 > C2.6, and C2.6 > C2.8 are part of the cola taste test experiment. C1.1 = organic label, C1.2 = no label information, C1.3 = regional label, C2.1 = Pepsi, C2.2 = Coca-Cola, C2.3 = Vita Cola, 2.4 = Topstar, C2.5 = drinking instruction Pepsi, C2.6 = drinking instruction Coca-Cola, C2.7 = drinking instruction Vita Cola, C2.8 = drinking instruction Topstar. As only positive t-statistic values are included in the results, only values from 0 (green) to +10 (red) can be compared.

As mentioned above, a label is expected to increase brain activity in the PFC; therefore, the first hypothesis was that the products marked with the organic label (C1.1) would lead to significantly greater activation in the PFC compared to the same products without any label (C1.2). For 93% of the subjects, this held true (see Table 1: C1.1 > C1.2). A similar result was expected for the comparison between the regionally labeled (C1.3) and the unlabeled food stimuli (C1.2). This could be proven as well, since 90% of the subjects showed a significant increase in brain activation (see Table 1: C1.3 > C1.2). As the organic label is well known and common in Germany, it was expected to induce the highest impact on PFC activity. It was further hypothesized that the organic label would cause stronger activation than the regional. This held true for 97% of the subjects (see Table 1: C1.1 > C1.3). In detail, this means that for 94% of individuals for the organic label and 90% for the regional label there was at least one channel that showed a significant increase in activation compared to a food picture without label information. But this increase cannot be transferred onto the whole group, because statistical parametric mapping was also done at the group level (SPM Level 2); however, it did not yield any significant results concerning the formulated hypotheses. A first explanation for this might be that some individual subjects showed varying numbers of channels with a significant increase in activation. Furthermore, the intensity of activation varied between different channels.

Cola Taste Test

The hypothesis for this second experiment was that the strong cola brands, Coca-Cola and Pepsi, lead to a higher activation in the PFC area than the weak brands Topstar and Vita Cola. This was hypothesized for both the taste test and for the viewing of the different cola brand pictures. Here, statistical parametric mapping at the individual level (SPM Level 1) was performed. Table 1 shows the results of the comparison between the different cola conditions. Resulting from the questionnaire, the taste of Pepsi (C2.5) and Topstar (C2.8) and their brand cues (Pepsi = C2.1, Topstar = C2.4) were compared in terms of PFC activity: 90% of the subjects showed an increase in activity while viewing the Pepsi picture compared to the Topstar picture (see Table 1: C2.1 > C2.4); however, this holds true for only 77% of the subjects in reference to taste (see Table 1: C2.5 > C2.8).

Coca-Cola was compared to Vita Cola in terms of ranking and taste. Coca-Cola was ranked as a favorite by the majority of the subjects, but Vita Cola led to differing opinions: 84% of the subjects showed increased activity in the PFC area while viewing the Coca-Cola brand cue (C2.2) compared to the Vita Cola brand cue (C2.3) (see Table 1: C2.2 > C2.3), but for drinking

(Coca-Cola = C2.6, Vita Cola = C2.7), 90% of the subjects showed increased activity. Coca-Cola and Pepsi were both mentioned as strong brands, Coca-Cola being chosen as the favorite by most of the subjects. Hence, a comparison between Coca-Cola (C2.2) and Pepsi (C2.1) also promised to yield significant results: 95% of the participants showed an increase in activity while viewing the Coca-Cola picture compared to the viewing of the Pepsi picture (see Table 1: C2.2 > C2.1). As the taste of Pepsi was, on average, indicated as the most pleasant followed by Coca-Cola, an analysis was also done for the drinking test of those two. From the analysis, drinking Pepsi led to increased PFC activity among 87% of the subjects compared to drinking Coca-Cola (see Table 1: C2.5 > C2.6).

For the cola taste test experiment, statistical parametric mapping on group level (SPM Level 2) was done as well, but did not yield any significant results concerning the hypotheses. It should be mentioned that, apart from taste, other subjective differences between strong and weak brands, not discussed in this article, also play an important and maybe a much stronger role when comparing strong versus weak brands. Due to the lack of results in relation to SPM Level 2 measuring in both parts of the experiment, it is not possible to transfer the findings to the whole group, so statements can only be made for the individual subjects. Nevertheless, the results show that the label of a food product or a strong brand has a significant influence on brain activity in the PFC for the majority of the subjects. However, general conclusions can only be drawn when there are significant results at group level (SPM 2).

Discussion

The aim of our experiments was to examine the feasibility of a mobile fNIRS system for neuromarketing research, especially during brand- and label-related decisions for food products. Summarizing the results, it can be seen that it is possible to measure PFC activity using mobile fNIRS for brand- and label-related experiments. Significant increases in PFC activity at the individual level were measured. The organic food label led to a higher activation than the regional label among 94% of the subjects; both labels led to an increase in activity compared to the same products without any labeling. This is consistent with prior work in this field, which showed that organically labeled products generated stronger brain activity compared to the same products not labeled (Fehse et al., 2017; Linder et al., 2010).

The challenge of confounders could also apply to the first experiment, that including the different food labels. The stimuli differ in respect of the amount of text on the label. Thus, apart from any preference, decision, or emotion, higher activation of the PFC for the organic and regional products could also be caused by the complexity of the stimulus, which includes visual complexity, reading versus no-reading, and additional associations that come up just because certain words are presented in addition to the food product.

The strong cola brands, Coca-Cola and Pepsi, led to an increase in activation while drinking and viewing the respective brand cues compared to the weak brands, Topstar and Vita Cola. These findings are in line with prior work. When it was believed that Coca-Cola was in the cup, significantly greater brain activation was measured, indicating that people prefer strong brands over weak brands (McClure et al., 2004). Furthermore, subjects gave different ratings, preferring Pepsi to Coca-Cola, and preferring both to Vita Cola and Topstar, despite the fact that the drinking cups contained exactly the same cola beverage throughout. This leads to the assumption that branding and information given through labels influence the value processing of our decisions, which is supported by prior findings (Grabenhorst, Rolls, & Bilderbeck, 2008). Consistent with our results, other studies have shown that popular food brands, and especially strong brands, lead to an increase of activation in different areas of the PFC (Fehse et al., 2017). Even the expectation of a pleasant taste leads to an increase in neural activity (O'Doherty, Deichmann, Critchley, & Dolan, 2002), which may explain why the majority of the subjects showed increased activity when just viewing the brand cues without yet having tasted the cola. In contrast to the study by Kühn and Gallinat (2013), a difference between Coca-Cola and Pepsi was found in this study: 95% of the subjects showed increased activity while viewing the Coca-Cola brand cue compared to the Pepsi. Indeed, without reference to a totally blind test with four different colas, it is difficult to conclude that the present study is in line with the "Pepsi paradox", meaning that people have strong preferences for Coca-Cola when they know about the brand, but if no brand information is available, the preferences are not reliable (McClure et al., 2004). Topstar and Vita Cola were set out as weak brands because, even if participants may have associations with them, they are not as popular as Coca-Cola and Pepsi. Topstar is a generic discounter brand and Vita Cola a brand from the old German Democratic Republic and not very well known in the western part of Germany. The brand cue of Vita Cola uses the slogan "with Citrus and Vitamin C", which may have confused some of the participants and could explain the different opinions the subjects had concerning the taste. Some subjects reported that they liked the citrus taste a lot; others indicated that Vita Cola had the least pleasant taste due to the lemon flavor.

Through the results of the questionnaire, it becomes clear that the subjects prefer labeled products since the majority of the subjects did not pick the unlabeled alternative in any of the choices. In more general terms, context factors like the organic and regional food label seem to help us choose between different food stimuli, which is in line with other studies (Meyerding, 2016; von Meyer-Höfer et al., 2015). Pearson et al. (2010) found that consumers seem to attribute high values, such as health and environmental concerns, to products, and therefore prefer organic and regional labels. This may explain our results. It is possible to say that food labels and strong brands influence participant’s decisions for or against a specific product. The influence seems to be strong enough at least to compensate for the fact that the participants consumed the same cola beverage in all four trials and not the different colas they were told they would drink, but still made clear decisions. Nevertheless, it must be said that the results of the questionnaire are not representative of the general public as all of the subjects were students. Buyers who purchase organic products often possess higher levels of education (Pearson et al., 2010), which may explain the approval of the two labels. Moreover, the products were not labeled with prices, which would, in a real-world buying situation, significantly affect the purchasing decision for a product (Plassmann, O’Doherty, Shiv, & Rangel, 2008). In modern society, food images are widely used to push food selection and intake (Beaver et al., 2006), which is why this study used food pictures instead of the actual products.

As this study could not gather significant results at the group level, we cannot extrapolate the single-subject results to the different areas of the PFC, as a consistent brain map of activated areas is missing. In other studies with very different tasks, PFC activity in the different areas was measured (Grabenhorst & Rolls, 2011; Grabenhorst et al., 2008; Heekeren et al., 2006; Herrmann et al., 2008; Plichta et al., 2011). The lack of results on a group level in this study may be due to a variety of factors, including the limitations of our experiments, the fNIRS technology itself and the general challenges of neuromarketing. These limitations will be discussed in the following.

Study Limitations

For this study, a headband was used to measure PFC activity instead of a whole head cap: this should ensure the best signal quality due to less disruption from hair and greater comfort for the subjects. There is only one band size and it was used for all the subjects. Because of the single band size, inter-subject variations in intensity, number of activated channels, and areas of activation may be explained by the differences in the band’s exact location on the skin (Sheena & Tom, 2009). For future studies, the use of a whole head cap is recommended, the optodes placed within the international 10–20 system (Zimeo Morais, Balardin, & Sato, 2018). On the other hand, differences might be due to the novelty of the fNIRS measurement and the fact that the technique is still not maturely developed. The strengths of the method are mobility and flexibility, which increases the usability for economic researchers in real-world situations. It is no longer necessary to place subjects in the tight and loud scanner. Furthermore, the temporal resolution for measuring direct blood oxygenation level changes related to neuronal activation is high, allowing the researcher to observe the hemodynamic response to neural activity over time (Tak & Ye, 2014). As the change in blood concentration results from increased activity in a specific brain area, the BOLD-like effect is measurable around 4–6 seconds after the stimulus; however, this is a long time to make decisions in the real world.

To improve the signal-to-noise ratio, it is further necessary to repeat every stimulus. The experimental design of this study was adapted to this effect; nevertheless, it might be that the chosen stimuli were not strong enough to cause a substantial hemodynamic response for every stimulus over time (Huppert, 2016). This might be due to the fact that the first part of the experiment used each label modification of the eight different pictures as one stimulus, because it was hypothesized that the impact of the label information would be stronger than the product itself. As the study consisted of two experiments, the second one showed the subjects each of the four different cola cues five times, and every differently branded cola beverage was consumed five times. For this experiment, the habituation effect in relation to the stimulus might explain a potentially lower hemodynamic response (Condon, McFadzean, Hadley, Bradnam, & Shahani, 1997).

It should also be mentioned that we used a significance level of 10%, which leads to results that are more significant than if we had used a lower significance level. This was done because our conditions do not differ extremely since most of them are pictures of products not leading to very strong reactions. This could be considered a limitation of the present study. With nirsLAB, we are not at the moment able to do corrections for multiple testing.

There are also some general limitations and weaknesses of the fNIRS measurement. It is less sensitive than fMRI (Piper et al., 2014), but neither measure is free of motion artifacts, the influence of blood pressure or Mayer waves, or disruption through body movement, all of which can influence the data quality (Tachtsidis & Scholkmann, 2016). To isolate the actual neural activity from these measurement noises, statistical analyses are required to avoid the occurrence of false positives and false negatives. This is difficult since a standardized statistical approach is still missing, and so a comparison of different results and studies is difficult (Hocke et al., 2018). Even if this study tried to minimize these effects by avoiding Mayer waves, adapting the stimuli time to the expected BOLD-like effect, avoiding huge body and head movements of the subjects, and filtering the data afterwards, we might still have affected the raw data quality. A weakness of the fNIRS measurement is that the spatial resolution is limited to 2 cm because the near infrared light is scattered by the tissue and has to pass through the scalp two times to go from the source back to the detector (Aasted et al., 2015). Acquiring data about deeper brain structures—e.g., the amygdala and other deep brain structures—that are assumed to be more directly connected to emotions than the prefrontal cortex is therefore not possible.

Furthermore, it has to be kept in mind that fNIRS measurement is not able to report absolute blood concentration changes but only relative differences due to changes in the cerebral blood flow (Jackson & Kennedy, 2013). Therefore, it remains unclear if activation in brain areas is an indicator of agreement or disagreement, approval or refusal, of the given stimulus (Beaver et al., 2006).

Challenges to Neuromarketing

Neuroimaging as a whole faces some critical pitfalls and challenges. One of the most fundamental challenges might be the discussion about ethical considerations in the context of neuromarketing research. Dealing with the sensitive data of the test persons, and at the same time fulfilling the scientific values of reliability, validity and transparency, requires sensitivity, especially when it comes to presenting the neuroscientific results to the public (Lim, 2018).

The use of imaging methods outside medical research often presents the far-reaching possibility of recording mental processes and thus gaining insights into the personality and threatening autonomy. The question arises as to whether it is possible to measure a person’s unconscious motives objectively.

In reality, however, the possibilities have so far been very limited. For example, images of the brain produced by fMRI are associated only with the activity of certain brain areas and related behaviors. An individual’s understanding of mental processes or the possibility of reading thoughts or drawing conclusions about the personality structure cannot be drawn. Furthermore, the fNIRS method used here is an imaging method, but it is only able to compare relative differences in the oxygen concentration of certain brain areas at certain points in time. Absolute and therefore individual values cannot be measured with this method.

We recommend addressing ethical concerns by conducting only experiments that are approved by an ethics committee and that comply with the Helsinki Declaration and the ethical principles for medical research on humans contained therein (World Medical Association, 2013), and by following the Code of Ethics of the Neuromarketing Science & Business Association (Neuromarketing Science & Business Association, 2013) and the ICC/ESOMAR International

Code of Conduct for Market, Opinion and Social Research and Data Analytics (ESOMAR World Research, 2016).

Concerns about a lack of reliability and the question of the generalizability of neuroscientific research always go hand in hand with the smaller sample sizes compared to traditional research methodologies. Due to the high costs and the complex study designs in fMRI experiments, it is common that only 6–10 participants are scanned; despite the use of within-subject designs, this is a small number for powerful statistical analysis (Lee et al., 2018; Plassmann et al., 2015). Increased use of fNIRS might be attempted, as this would make it easier and more cost-effective to examine significantly larger groups of test persons in the future.

What remains an issue in almost all empirical neuromarketing applications is the problem of reverse inference—linking a specific brain activity one-to-one to a behavioral assumption or a psychological process (Plassmann et al., 2015; Poldrack, 2011). Brouwer, Zander, van Erp, Korteling, and Bronkhorst (2015) describe some of the challenges when assessing mental state using neurophysiological methods. One challenge is that obtaining ground truth can be complicated in research on mental states and emotions. Neither cognitive nor affective states are easily detectable from behavior, which is also a challenge when interpreting the present study. When attempting to quantify cognitive and affective states based on neurophysiological signals, the researcher aims to link a particular psychological state to physiological signals. Unfortunately, it is not a priori certain how, or to what degree, states defined from a psychological perspective map onto neurophysiology. It may be not the emotion but probably the associated (future) activity that defines the physiological response.

So how can it be ensured that the brain maps of neural activation not only describe the participants' brain while watching colorful pictures, but that these are theory-based cognitive connections in relation to explicit stimuli? Data from neuronal activity in particular possess an air of truth and objectivity that can be questioned, as in the suggestion that neuronal activity patterns reveal true emotional involvement, even if the participants' reports indicate otherwise. The quantification of mental state using neuroimaging methods such as fNIRS is a popular but also challenging project, which requires the integration of knowledge from a variety of scientific fields. Overarching fields are neurophysiology, which provides knowledge on the processes of the nervous system and how these can be measured, and experimental psychology, which provides techniques to discriminate and quantify mental states or emotions (Brouwer et al., 2015). With still little literature of high quality and a lack of training and expertise, the interdisciplinary network between researchers gains in importance, and for newcomers in particular this area is hard to access, making it even more difficult to start neuromarketing successfully (Lee et al., 2018).

When designing an experiment, we need to check whether the examined mental states of interest might co-vary with other factors that are not significant to the state of interest. If the confounding factors affect the neurophysiological signals on their own, this effect might be mistaken by an effect of the mental state of interest. Another pitfall could be that if a difficult condition is presented before an easy one, the higher activation in the former may not be related to task difficulty or emotion but to not yet being used to the experimental setting, the physical activity, or other related effects. Different conditions in the experiment ideally only differ with respect to the state of interest (Brouwer et al., 2015; Huppert, 2016). However, the business case, and the identification of the benefit of using neurophysiology, is not an easy task and might develop with time. Carefully controlled laboratory experiments allow the researcher to verify which neurophysiological measures are linked to emotions or mental state. In an applied research field such as marketing, where we want to use neuroimaging, this is not sufficient. It is also important to mention under what circumstances and in what ways neuroimaging can be helpful. This is not easy, since we need to realize that normally there are alternative methods to retrieve the mental state information under investigation. Why do we use neuroimaging to estimate the degree to which a consumer likes a product when they can be asked directly? Is there empirical evidence that such experiments will better predict and understand which product the consumer will buy? While the basic idea is that we have another channel of information available ‘for free’, since participants do not need to pay attention to or make a conscious effort to convey information about their mental state, there are costs involved in buying and wearing the equipment, calibration procedures, and so on. Compared to other sources of information, these costs are relatively high, especially for the measurement of brain activity. One way to add value from neuroimaging results might be to combine different methods, including more traditional methods such as choice-based conjoint analysis, with neuromarketing methods such as eye-tracking and neuroimaging (Brouwer et al., 2015; Meyerding, 2016; Meyerding & Merz, 2018). This approach could significantly advance neuromarketing research, as the results of more subjective tools (neural activity inside the brain) might be combined with more objective methods (neural activity outside the brain) (Lim, 2018), thus enriching all research fields through a more dynamic understanding of human behavior and the underlying mental processes (Lee et al., 2018; Plassmann et al., 2015).

In real-life scenarios, the discussion on confounders is related to that on alternative methods to discover information about cognitive and affective states. Comparably reliable information from neuroimaging is expected when there is little noise from body movements, as in the present experiment, and when estimates can be based on a lot of data. Additionally, relatively reliable information can be expected when the relationship between neurophysiology and the mental state of interest is clear and well estimated, and the experimental design is based on a theory so that it can be administered by direct stimulation of the associated neurophysiological signals (Brouwer et al., 2015; Plassmann et al., 2015). In an applied field of research such as marketing, we further need to design more realistic experiments in the open field and test whether they have additional value. However, because of confounders in real-life studies, it will be challenging to connect neuroimaging results directly to cognitive and affective states. Therefore, special care is recommended in relation to conclusions about cause and effect, which limits the application of neuroimaging methods for marketing research (Brouwer et al., 2015) and is also an issue in the present study. However, attempts to orient the experiments more toward real life and the observation of spontaneous brain activity in naturalistic environment settings, instead of waiting for the response of participants to stimuli, could change the focus from specific brain regions toward a new understanding of dynamic brain networks. Mobile and flexible neuroimaging tools like the fNIRS system could be pioneers in this field.

Future Research

To achieve more detailed information about cortical processes during exposure to stimuli, it might be useful to combine neuroscientific and traditional marketing methods—for example, fNIRS with other measurement methods like eye-tracking, questionnaires or, as some other studies have done, electroencephalography (EEG), an electrophysiological method to monitor electrical activity in different areas of the brain (Fazli et al., 2012; Herrmann et al., 2008; Lee, Fazli, Mehnert, & Lee, 2015). As EEG focuses on a spontaneous electrophysiological response to a stimulus, the temporal resolution is very high. fNIRS measures the hemodynamic response to a neural activity with a better spatial resolution. The combination of the two methods could compensate for their individual weaknesses and lead to a better understanding of the underlying neural processes of behavior.

Further research should use the whole fNIRS cap instead of the headband to achieve significant results at group level due to identical positioning of the near infrared light sources and detectors on every participant’s head. Since the fNIRS cap uses the same standardized measurement points on the head as the EEG (10–20 system), data quality could be significantly improved (Sheena & Tom, 2009).

To the best knowledge of the authors, this is the first study to combine fNIRS measurement with brands and food labels, opening up possibilities for the extended application of fNIRS in the natural environment outside the laboratory, such as a supermarket. The results indicate the possible future feasibility of fNIRS measurement for neuromarketing research, especially as it could someday provide information about consumers' thoughts, memories, evaluations, and decision-making strategies without having to ask them directly (Plassmann et al., 2012). This reduces the biases of questionnaires, as social desirability and other influences can be avoided (Fehse et al., 2017). Although this new neuroeconomic tool is promising, it should be noted that a single brain area is always involved in more than one task, and not all experimental designs allow a clear delineation between them. Especially in consumer neuroscience studies related to branding, this reverse inference has been mentioned as a major problem and a reason why future studies should focus on the brain as a dynamic network rather than on individual brain regions (Plassmann et al., 2012).

An appropriate statistical standard for fNIRS measurement to compare brain activation with a functional and detailed brain map would most likely improve neuroeconomic research and the value of the results substantially (Aasted et al., 2015; Tachtsidis & Scholkmann, 2016)

Conclusions

Neuromarketing and neuroimaging are not and will not in the near future be more cost effective than conventional marketing research methods, such as stated preference techniques. However, continuing developments such as the technique used in this study indicate that neuromarketing will soon be able to reveal hidden data about consumers' preferences for product characteristics such as labels and brands. Although these data might boost post-design sales efforts, the real potential lies in the use of neuroimaging during the design procedure, which might affect a wide variety of goods, including food (Ariely & Berns, 2010). To summarize, this study pioneered using fNIRS measurement to test the effects and impacts of brands and labels on prefrontal cortex activation. The labeled products led to a significant increase in neural activity in the PFC compared to the same products without a label. Furthermore, the strong cola brands Coca-Cola and Pepsi, when apparently being consumed and viewing the respective cue, generated a significant increase in PFC activation compared to the weak cola brands Topstar and Vita Cola. The impact of the brands seems to be so high that the subjects did not notice that the four soft drinks they were consuming were actually all the same. As it was not possible to generate group data to compare the results of the single subjects, no classification of the different PFC areas could be performed. Thus, it is advised to use the full fNIRS cap instead of the headband in future experiments.

Nevertheless, the feasibility of fNIRS was shown in this study. Mobile fNIRS embodies an innovative tool to achieve insights into customers' brain activities, which provides significant advantages compared to fMRI. Its potential for neuromarketing and economic research is highly promising. Further research should be done in more naturalistic environments, with improved signal quality and standardized brain mapping to compare results.

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Article 2:

Assessing Label Frames and Emotional Primes in the Context of Animal Rearing – Response of an Explorative fNIRS Study

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4.2 Assessing Label Frames and Emotional Primes in the Context of Animal Rearing – Response of an Explorative fNIRS Study

Abstract

Against the background of rising societal interest for sustainable food and nutrition choices, food labels gain importance in providing important information to consumers. However, little is known about how the differences between quality frames in labels are evaluated and how priming might serve as an anchor for label perception. This study aims to observe the neural reaction of this in the context of differently framed food labels for products of animal origin, claiming the presence or absence of an additional quality aspect and under the impulse of emotional priming. In an explorative set-up, we measured the neural prefrontal cortex activity of 26 participants with the neuroimaging technology fNIRS. An idyllic prime and a prime related to a label claiming an additional product quality led to increased neural activity in the OFC and dlPFC. Shedding light on what elements are of importance to identify products that meet consumers' requirements in terms of quality aspects, this could indicate that the prime stressed the meaning of the label, which strengthens the argument to positively phrase and anchor frames regarding quality attributions as opposed to negative declarations. It further demonstrates the ability of fNIRS to capture processing through labels and primes in the context of consumer behavior.

Keywords: consumer neuroscience; food labeling; neuromarketing; message framing; meat label; quality attributes; sustainability

Introduction

Overall, societal interest for sustainable food and nutrition choices is growing. Taking climate gases as one specific example, roughly 17% of the greenhouse gas emissions can be attributed to the agri-food sector (Ivanova et al., 2017). Given the daily complexities and interconnectedness of agri-food systems, what we eat affects not only environment, but also the food security, safety and human health (Alsaffar, 2015; Myers et al., 2013; Nemecek, Jungbluth, i Canals, & Schenck, 2016). Therefore, sustainable lifestyle and consumption behaviors are becoming more and more important and should be further encouraged. Against this background, not only companies are working to become more sustainable and to gain better corporate social reputations (Castaldo, Perrini, Misani, & Tencati, 2009; Conca, Manta, Morrone, & Toma, 2021). Also, consumers are increasingly interested and are demanding more sustainable agricultural and food products. Taking the context of products of animal origin, there is for example growing societal concern regarding animal welfare in the intensive agricultural production. On the one hand, consumers are concerned that not very animal-friendly production systems could impact food safety, product quality, and their own health (Alonso, González-Montaña, & Lomillos, 2020; Grunert, Sonntag, Glanz-Chanos, & Forum, 2018). On the other hand, it is not always easy for consumers to evaluate the products that meet their requirements in terms of process quality aspects, e.g. with regard to sustainability or animal welfare (Ikonen, Sotgiu, Aydinli, & Verlegh, 2020).

Often process quality information is provided by labelling frames. They provide additional relevant and easily accessible information (e.g. in the form of eco-labels or food labels) to consumers to help them identify certain desired or undesired product properties (Alonso et al., 2020; Horne, 2009; Ikonen et al., 2020). Eco-labels e.g. are thought to increase sustainable consumption patterns, because they simplify consumers' decision-making process with regard to the property under consideration (e.g. animal-welfare) (Horne, 2009). In this context, the framing of quality aspects in the sense of the phrasing, wording, and formulation gains importance (Messer, Costanigro, & Kaiser, 2017). Often, consumers are not aware that, depending on the frame, they may perceive this information very differently (Levin, Schneider, & Gaeth, 1998; Shan, Diao, & Wu, 2020). If, e.g., certain product properties describe an absence of a quality aspect or, conversely, the presence of an additional quality aspect, this influences consumers' evaluation, which may be important in the processing of the overall product information (Kahneman & Tversky, 1979; Levin et al., 1998; Messer et al., 2017; Van Dam & Jonge, 2015).

Additionally, product evaluation is triggered by emotional primes that may serve as an anchor for consumers (Kahneman & Tversky, 1979, 1991; Tversky & Kahneman, 1974). Despite the high social relevance, little is known about the role that label framing and priming play for products with sustainable food labels and how this is affecting the evaluation of the declared process quality. Therefore, this study investigates, in an explorative neuroimaging set-up, the effect of label frames claiming the absence or presence of a quality aspect combined with a prime from the context of animal rearing. The question is whether differences with regard to the evaluation of product quality can be traced back to the priming of information.

Background

Labels can highlight a further product quality in the sense of the existence of additional attributes (e.g. fair-trade standards) or the absence of negative aspects (e.g. GMO-free) (André, Chandon, & Haws, 2019). Both possibilities then imply a higher or better quality compared to other products in this segment. However, labels can also be used the other way around by underlining a lower product quality. They then declare the presence of rather negative aspects or the absence of positive characteristics (e.g. health risks when smoking), and they then imply that the products appear with lesser or reduced quality than the average product (André et al., 2019; Grankvist, Dahlstrand, & Biel, 2004; Liaukonyte, Streletskaya, Kaiser, & Rickard, 2013).

With regard to priming, marketing approaches often use pictures as primes for product presentation because, compared to textual information, they evoke a greater emotional response in consumers, thereby influencing consumers' emotional evaluations about the product (Minton, Cornwell, & Kahle, 2017; Noar et al., 2016). Unattractive or deterring pictures might emphasize undesirable consequences that are associated with buying or consuming this product, leading to negative emotional reactions (Levin et al., 1998; Rosenblatt, Dixon, Wakefield, & Bode, 2019; Shan et al., 2020). One real-life example are shocking pictures combined with health warning messages on tobacco packages, highlighting the negative consequences of smoking behavior and leading to strong negative emotions and perceptions (Noar et al., 2016; Rosenblatt et al., 2019). In contrast, beautiful or nice pictures can emphasize the desirable profit or benefits that are associated with buying or consuming a product, leading to positive emotions about the product (Rosenblatt et al., 2019; Shan et al., 2020). This approach is often used for products of animal origin, where idyllic or romanticized animal pictures aim to give the consumer a good feeling about the product. However, this does not always correspond to the actual husbandry systems, which is why there is increasing discussion about the use of more realistic images in the marketing of products of animal origin, although they often carry negative associations (Busch, Schwetje, & Spiller, 2015).

Consumers are often unaware of the fact that they are influenced by stimuli that go beyond the sensory taste attributes of a product, which is that product priming and label framing might influence their perception of the product and, in the long run, their behavior (buying vs. not buying the product) (Stasi et al., 2018; Tversky & Kahneman, 1981). Therefore, the provided product and label information and their pre-priming unconsciously serves as an anchor function in the customers' effort to find satisfactory product solutions for their needs (Kahneman & Tversky, 1979; Tversky & Kahneman, 1981). The emotional loadings may impair connotative evaluation, thus indirectly influencing the perception of frames for labels and their information processing. Therefore, it would be interesting to better understand the emotional and associative links between the evaluation of label frames and anchored, stored emotional information to understand consumer perception.

For this reason, it is of interest to examine consumers' perception by not "asking" them directly but by using an indirect measurement approach that allows the investigation of unconscious processes of people (Meyerding & Risius, 2018). One new approach to this is the investigation of consumers' neural responses (Stasi et al., 2018). As opportunities grow to observe the neural manifestation of constructs such as "framing" and "priming" in the living brain,mobile, cost-effectively and without great effort (Meyerding & Mehlhose, 2020), the purpose of this study was to determine whether there are differences in the neural perception between differently framed messages claiming an absence of a quality aspect or presence of an additional quality aspect. For this, we used labels with regard to the mediation of the presence ("antibiotics"), absence ("antibiotic-free"), or of no additional information of antibiotics in the production system. These label presentations were further primed with rather idyllic vs. rather oppressive pictures of poultry production systems (free-range vs. indoor). We chose this as a context for our labels to follow up on the societal demand to combat the worldwide problem of antibiotic resistance through the establishment of a labeling regime for so-called 'antibiotic-free' animal products (Busch, Kassas, Palma, & Risius, 2020; Landers, Cohen, Wittum, & Larson, 2012; Prestinaci, Pezzotti, & Pantosti, 2015). This is discussed by food manufacturers worldwide, and companies in the US and Denmark are pioneers in establishing antibiotic-free policies and labels and claim the absence of antibiotics in the rearing of the animals (Mollenkopf et al., 2014). It has gained in importance in view of the fact that consumption of chicken meat is continuing to rise worldwide (in Germany, meat consumption as a whole is slightly declining), and as a result, production capacities are also continuously increased (BLE, 2020).

Against the above-described background, we hypothesized that it is possible with fNIRS to measure differences in the prefrontal cortex neural activity between the primes alone and between the differently framed labels in combination with the primes. To investigate the expected differences in neural response of test persons, we applied a new and innovative optical imaging method in consumer neuroscience, the functional near-infrared spectroscopy (fNIRS). This study follows up on the recommendation of (Sánchez-Fernández, Casado-Aranda, & Bastidas-Manzano, 2021) to apply fNIRS in studies related to sustainable consumer behavior.

Materials and Methods

FNIRS technology

Functional near-infrared spectroscopy (fNIRS) visualizes brain activity through hemoglobin's ability to absorb light (Jackson & Kennedy, 2013). With sources of near-infrared light in specific wavelengths (760 nm and 850 nm) penetrating the human tissue, the differences of cerebral oxygenated hemoglobin (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb) can be measured and made visible, which allows drawing conclusions about the neural activity beneath the surface of the brain at certain times (Ferrari & Quaresima, 2012). Beyond that, fNIRS technology provides several advantages over functional magnetic resonance imaging (fMRI), which is the best-known and frequently used imaging technique so far to acquire insights into the human brain: fNIRS is mobile and comfortable, which enables an extensive use of this technology, especially for more realistic experimental settings, where greater flexibility of the test persons is required. Compared to other neuroimaging methods, it also has a lower sensibility, which results in a greater robustness against body movements and thus extends the field of application to outdoors or unconstrained environments (Balardin et al., 2017; Pinti et al., 2018). Further, the fNIRS mechanism is similar to the principle used in fMRI measurements (BOLD signal), which allows the fNIRS signal to be compared to the fMRI signal (Masataka, Perlovsky, & Hiraki, 2015).

Participants

26 students were recruited to take part in this study. Of these, 15 were male and 11 were female. The average age was 22.9 years. All participants had normal or corrected-to-normal vision. They participated voluntarily in the experiment, but two vouchers were raffled among all participants as an incentive. Before the experiment started, all participants were informed about the experimental setting and the mobile fNIRS technology. Although fNIRS is a non-invasive method and does not represent a risk to the participants, they were informed that they could

stop the experiment at any time with no consequences for them. All test persons gave their consent to participate in the study. The whole experiment was conducted according to the APA's Ethics Code and is in line with the Declaration of Helsinki. The procedure and the use of fNIRS were approved by the university's ethics committee.

Stimuli

Our experimental stimuli consisted of twelve different images from poultry farming systems which were used as primes. Six of them showed different impressions from free-range poultry farming systems, with chickens in a rather idyllic and natural environment (idyllic prime). In contrast, the other six pictures showed animals in a confined, dark room or in large fattening facilities (oppressive prime) (Figure 1).

Figure 1: Six images from free-range or indoor-poultry farming systems showing chicken in an idyllic and natural environment (idyllic prime) or, in contrast, animals in a confined, dark room or in large fattening facilities (oppressive prime).

For the differently framed labels, we used the picture of a meat package with whole chicken breasts, on which we placed the different labels to make their use more realistic. The first meat packaging image had a self-designed green label in the upper left-hand corner with the text: "Antibiotika frei" (antibiotic-free). This label information claimed the additional product quality (as an absence of a rather 'negative' aspect) (Label+). The second meat packaging image had a red label and the information "Antibiotika" (antibiotics) on it and claimed a lower product quality (as a declaration of usage of rather negative aspects) (Label–). The third image contained the meat package without any label information and served as a control condition (Figure 2). We did not provide any further information about the terms "antibiotics" and "antibiotic-free" and their definitions to allow the labels to stand in contrast with each other, but we stressed their meanings and differences through the use of the colors green and red. The meat package was bought at a German retail store and photographed for the experiment. We deliberately refrained from making any significant changes to the image and only altered the expiry date and removed the condensation within the packaging using a graphics program (Photoshop ®). We then used the same software to add the labels.

Figure 2: The meat package with a whole chicken breast was used to depict the label information.

Note: The first label (green) claimed an additional product quality through the absence of antibiotics ("antibiotic-free") (Label+). The second label claimed a lower product quality through the use of antibiotics ("antibiotics") (Label−). The third image had no additional label information and served as a control condition.

Experimental Design

The experimental design consisted of six trials. In every trial, each of the six pictures from free-range or indoor-poultry farming was presented one after the other in randomized order (6x4 s). These six pictures were followed randomly by one of the three labeled meat packages (15 s) and a small break (4 s) afterwards. In total, each meat package was shown six times, three times with the six rather idyllic and three times with the six rather oppressive primes before. In total, the experiment lasted for 13 minutes and 26 seconds (Figure 3).

To assure the same circumstances for every participant, the experiment was conducted in a small, windowless room. Care was taken that the light did not fall directly on the fNIRS set-up or on the screen in order not to influence data quality and the participant's view. The experiment was conducted on a 13-inch laptop with participants placed at half a meter distance in front of it. Participants had to passively view the images.

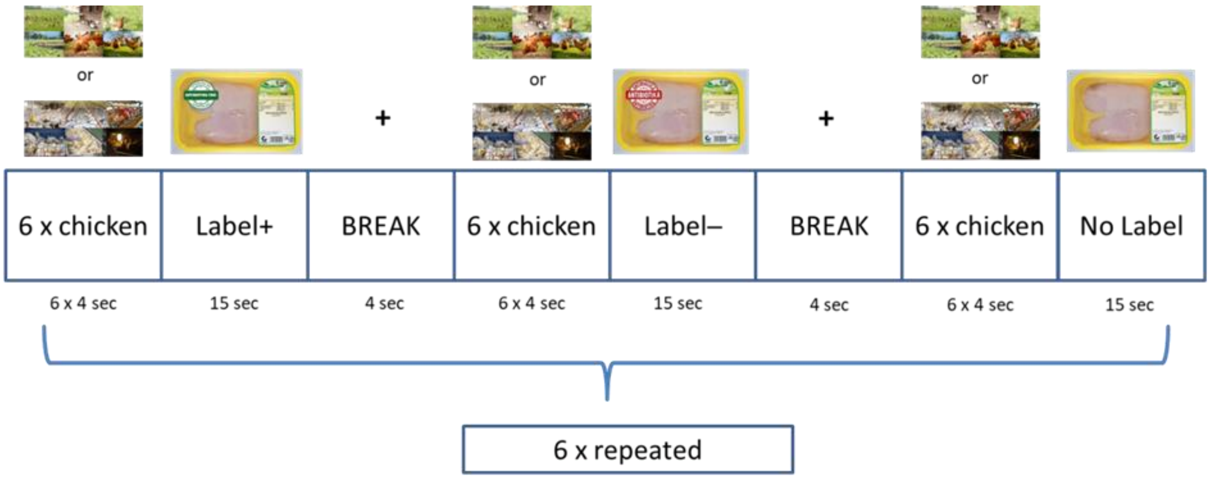

Figure 3: Schematic representation of the experimental design

Note: Label+ represents the green "antibiotic-free" label, which claims an additional quality aspect. Label− represents the red "antibiotic" label as it claims reduced quality. The prime before the labeled meat packages consisted of six chicken images. Those were three times the six rather idyllic and three times the six rather oppressive images. During the break, the participants saw a fixation cross. The experimental design was completely randomized.

Data Collection and Analysis

Hemoglobin data of the prefrontal cortex were obtained using a mobile fNIRS measurement system (NIRSport; NIRx Medical Technologies, Berlin, Germany). This is a two-wavelength continuous wave system that collects data in parallel at a sampling rate of 7.81 Hz. In this experiment, we used a neoprene headband that consisted of eight sources and seven detectors which were placed at a distance of three centimeters to each other. This resulted in 22 measurement channels that covered parts of the prefrontal cortex, namely Brodmann areas 9, 10, 11, and 46, which are related to the orbitofrontal (OFC), the dorsolateral (dlPFC), and the frontopolar prefrontal cortex (FPC). A schematic representation of the topographical layout with the channels is shown in Figure 4.

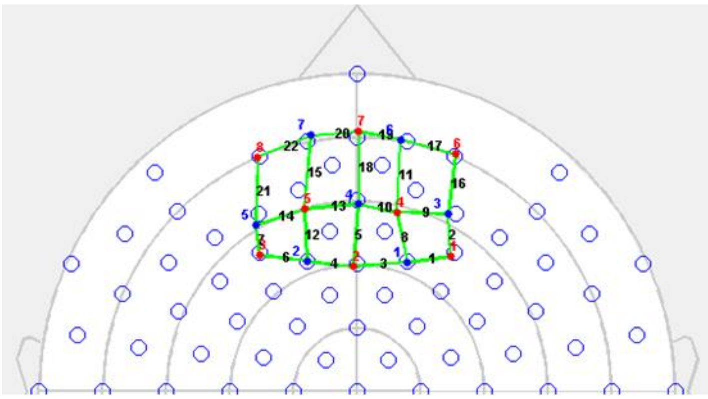

Figure 4: Schematic representation of the topographical layout.

Note: Red numbers symbolize the sources (1–8), blue numbers the detectors (1–7), and the black areas in between are the channels (1–22) representing the different brain areas of the prefrontal cortex.

The headband was placed on participant's forehead and, after checking the signal quality, we began collecting data (both with NIRStar, version 15.0). The images within the experimental design were presented using the software NIRStim4. All the following steps concerning raw data preprocessing and modeling of the neural activity were performed with the software nirsLAB version 2017.6. First, we preprocessed the raw fNIRS signal. The data was band-pass filtered to remove strong artifacts (e.g. heartbeat, etc.). Then, through a modified Beer-Lambert law, we transformed the raw optical density signals into the hemoglobin concentration changes (oxy-Hb and deoxy-Hb). We chose the hemodynamic response function to model the neural activity. Data analysis was performed only with oxy Hb because it seems to correlate more strongly with the cerebral blood flow (Hoshi, Kobayashi, & Tamura, 2001). We performed a channel-based group-analysis based on a general linear model (GLM) analysis of the hemodynamic-state time series during the experimental conditions. We used the GLM for statistical parametric mapping level 1 to detect the hemodynamic response of oxy-Hb for all 22 channels under all conditions at the individual level. At the group level, we performed statistical parametric mapping level 2 using the generated beta-value for each subject, channel, and condition to run one-sided t-tests to detect the significantly activated channels of the respective two compared conditions. The activation threshold was set to $p < 0.1$. We calculated contrasts for the emotional primes themselves (idyllic vs. oppressive poultry images) and for the combination of the differently framed labels with the previous primes (Idyllic & Label+ vs. Idyllic & Label−; Oppressive & Label+ vs. Oppressive & Label−; and the same compared to the No-label condition). Depending on which of the experimental conditions had a larger relative effect, this resulted in positive or negative t-values for significantly stronger activated channels during this contrast. Those t-contrast activation maps were afterwards plotted on a standardized brain model, which is included in the nirsLAB software.

Results

The results for the primes themselves showed that the contrast of the more idyllic free-range poultry farming images resulted in a significant increase of neural prefrontal cortex activity in *channel 20* compared to the rather oppressive images of indoor-poultry farming ($t(26) = 1.78$, $p \leq 0.1$, $d = 0.494$). This corresponds to Brodmann area 10 and contributes to the OFC and FPC (Figure 5).

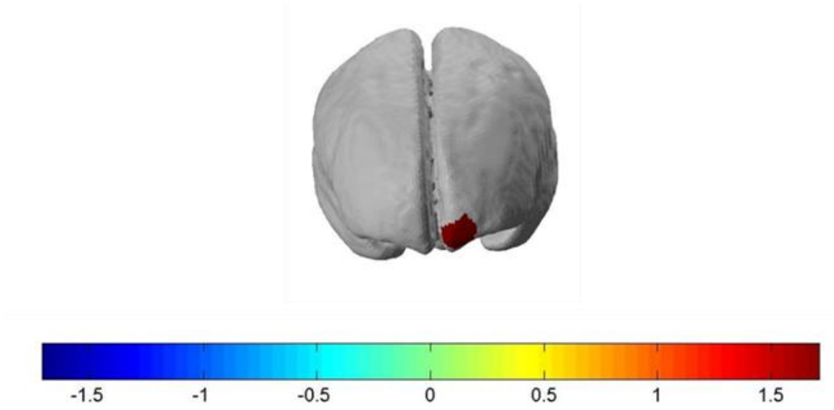

Figure 5: Thresholded SPMt image: Increased oxy-Hb neural activation in *channel 20* ($t(26) = 1.78$, $p \leq 0.1$, $d = 0.494$) when participants saw the idyllic, free-range poultry farming images compared to the rather oppressive images of indoor-poultry farming.

When it comes to the neural effect of the primes related to the differently framed labels, we detected a significant increase in neural activity when participants saw the green "antibiotic-free" label compared to the red "antibiotic" label with the earlier idyllic prime. More precisely, *channel 3* ($t(26) = 1.71$, $p \leq 0.1$, $d = 0.474$) showed increased neural activity, which corresponds to Brodmann area 9 and is part of the dlPFC (Figure 6). This significant difference in the oxy-hemoglobin level was measured amongst all participants. All other label contrasts were performed but did not hold significant results.

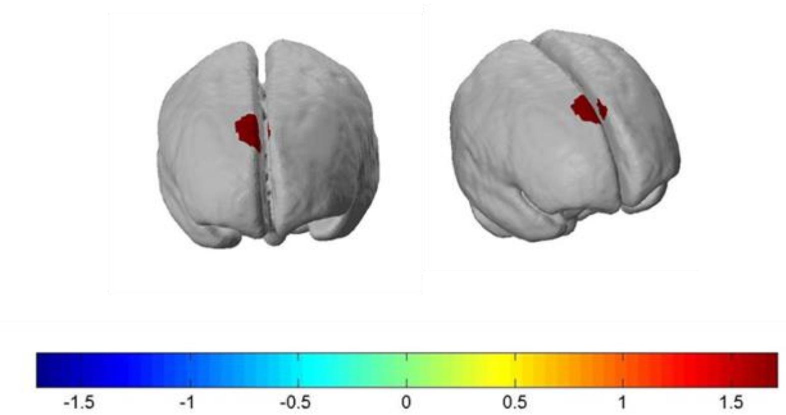

Figure 6: Thresholded SPMt image: Increased oxy-Hb neural activation in *channel 3* (t(26) = 1.71, $p \leq 0.1$, d = 0.474) for the green "antibiotic-free" label compared to the red "antibiotic" label, both with the earlier idyllic prime.

Discussion

This study used fNIRS to examine consumers' neural perception of differently framed food labels and primes related to different types of poultry rearing. The results showed that it is possible to measure differences in the prefrontal cortex neural activity between primes alone and between the differently framed labels related to the primes.

More specifically, the rather idyllic prime showed a significant increase in BA 10 (OFC/FPC) activity compared to the rather oppressive one. This is in line with another fNIRS study that achieved a significant effect in the same brain area for the evocation of positive and negative feelings caused by different aesthetically pleasing images (Kreplin & Fairclough, 2013). Moreover, several other studies that examined the neural perception of art found that the OFC is activated when viewing authentic or aesthetic pictures and images (Huang, Bridge, Kemp, & Parker, 2011; Kirk, Skov, Hulme, Christensen, & Zeki, 2009). Further, there is evidence that the OFC is associated with the evaluation of hedonic values from different sensory stimuli (Kirk et al., 2009; Kringelbach, 2005). Due to our explorative experimental set-up, we can only speculate at this point about the meaning of our results, but it is possible that the idyllic pictures evoked a rather pleasant emotional processing.

When it comes to the neural prefrontal cortex activity of the differently framed labels in relation to the primes, we found significantly increased activity in the dlPFC related to the idyllic prime when participants viewed a label claiming an additional product quality compared to a label claiming lower product quality. In contrast, the label that highlighted the presence of a negative characteristic did not provoke a reaction by the means of a negative neural response, but rather a neutral response. One study in the context of message framing found a stronger neural effect of positively framed messages compared to negatively framed ones, another found neural activations in similar brain regions (Krawitz, Fukunaga, & Brown, 2010; Vezich, Katzman, Ames, Falk, & Lieberman, 2016). Regarding the transfer of additional product quality, it may be an important finding to anchor the process information in a positive manner to target the intended meaning with regard to increase process transparency. This should be further validated in future studies.

Against the background of sustainability and meat consumption, our results can shed light on what elements are of importance to identify products that meet consumers' requirements in terms of quality aspects. Framing and priming of products can evoke preference shifts, which can influence consumer behavior. Within the process of labelling, those effects are important to consider as they are transporting a preferred quality aspect. E.g. the less sustainable products or aspects of a product (in this case the use of antibiotics) could lead to a greater behavior shift in the sense of an avoidance of this product overall, than e.g. highlighting the positive and sustainable aspects of a product, which only provides the consumer with knowledge, but does not necessarily result in an action (Grankvist et al., 2004; Ölander & Thøgersen, 2014; Van Dam & Jonge, 2015). We cannot clarify the behavioral aspects with our data, but we recommend to study this further.

The main intention of the study was to reflect consumer neuronal response to a frame and to understand the evaluation process of quality better, given different established frames. The evaluation process and the anchoring of information may be very important, especially with regard to an educative-intensive credence good, such as sustainable food quality. Studying this evaluation process in depth by using the novel technology of fNIRS and to find out whether it is generally possible to measure the cognitive modulation of these aspects with fNIRS was therefore important.

Given the novelty of the approach and due to the novelty of fNIRS as an imaging technology for examining consumer behavior, this study is of an explorative character. This does not yet allow us to draw conclusions on the relationship of consumers' neural responses and the actual behavior. The study did not include a consequent choice-test which would have allowed for such conclusions. In upcoming studies, it would be useful to add behavioral measurements that would allow us to better explain and embed our results within the underlying brain mechanisms or neural structures. A general explanation of the results with regard to the classification and connection of the neuroimaging results is therefore not possible at this time, because in the area of neuroeconomic and consumer neuroscience mental processes and underlying brain functions are still much less understood. As such, we can only make first suggestions at the content level. However, it is known that BOLD activations observed when passively viewing images can predict subsequent choices, which justifies our initial considerations in this regard (Levy, Lazzaro, Rutledge, & Glimcher, 2011). We aim to start to evolve into consumer behavior and consumers' neural actions, which is why our results should be seen as first explorative insights on what might eventually be possible and what other studies on sustainable marketing and consumer information can build upon.

This study sheds some light on the importance of priming, labeling frames and also on the novel measurement technology fNIRS in the context of consumer behavior and food labeling. Our study provides an additional step in using more indirect measurement approaches to understand consumer behavior, such as, in our case, to investigate the neural responses to emotional primes and differently framed food labels. As such, our study is also in line with, e.g. the study by (Burns et al., 2018), which found that fNIRS is a reasonable set-up to measure message framing-related effects in the prefrontal cortex. The use of mobile fNIRS is an appropriate neuroimaging method to detect neural effects of framing and priming in food and sustainability contexts, and it demonstrates that differences are detectable and measurable, especially when stimuli might evoke strong and differing emotional reactions.

However, due to the novelty of fNIRS, there are still many inconsistencies between the effects and results reported in different studies, and a proper comparison is therefore still challenging (Bendall, Eachus, & Thompson, 2016). Further, there are also technical limitations of fNIRS compared to fMRI: Although fNIRS is less sensitive to head and body movements, the quality of the results might be influenced by extracerebral confounds (Tachtsidis & Scholkmann, 2016). In addition, there is poorer spatial resolution compared to fMRI due to the fact that fNIRS measurements are based on hemoglobin concentration changes measured through near-infrared light, compared to fMRI where they are measured through the changes in magnetic fields (Quaresima & Ferrari, 2016). In fNIRS, this leads to a low light penetration depth, which means that only the superficial areas of the brain can be measured, such as the prefrontal cortex. This makes it more challenging to precisely localize the activated areas, as they are difficult to distinguish from one another.

This study faces several limitations: Our labels were fictitious, i.e. they were unknown to the participants and were not supplemented with additional or explanatory information. This could have caused some uncertainty or confusion concerning the meaning of the labels (Liaukonyte et al., 2013). Nevertheless, the labels were inspired by existing label schemes detected in markets in the US, Italy, and Germany prior to the survey, to ensure consumer familiarity with the overall topic. Additionally, this way, we could ensure that consumers all had the same (i.e. no) attachment to the label and were not co-mediated by different knowledge or trust levels. Thus, using a hypothetical label allowed us to study the effect of the frames in combination with the priming, which could have been 'biased' if we had used an existing label.

Another limitation might be that, although other studies have used colors to underline the content of their label information as well, it is quite possible that the perception of the label was intensified by the different colors we gave them. The green ("antibiotic-free") label might have increased the perceived healthiness of the product and therefore led to a stronger neural activation compared to the red color of the "antibiotics" label, which could have had an additional warning effect (Schuldt, 2013). The selective effect of color in reaction to a frame and process information should be clearly differentiated in upcoming studies. Further, in this study, we focused on the neural responses to the stimuli and did not strengthen the findings through a behavioral task (e.g. a choice experiment) by the participants. Using a behavioral task would provide not only a neuronal response but also preference schemes put in action by matter of a choice. Given budgetary limitations and a profound work on consumer behavior in choice experiments in reaction to rearing conditions (e.g. Risius & Hamm, 2017; Schulze, Spiller, & Risius, 2021), this innovative study aim was to focus on evaluation mechanisms that take place within the evaluation process. In the future, such additional measurements should be carried out to investigate the question to what extent fNIRS can replicate or supplement the results of traditional instruments.

Conclusion

To the best of our knowledge, this is the first study that has investigated consumers' perception of primes and their influence on differently framed food labels on a neural basis and with the novel brain imaging technology fNIRS. Our results shed light on what elements are of importance to identify products that meet consumers' requirements in terms of quality aspects. The idyllic prime itself and the prime related to the label that claimed an additional product quality led to increased neural prefrontal cortex activity. The idyllic prime might have enforced the meaning of the label, which could indicate that, in order to target an additional product quality, the process information should be anchored in a positive manner. Our results further demonstrate that mobile fNIRS is an appropriate neuroimaging method to capture emotion-related processing through labels and primes in the context of agricultural production systems and food contexts. In addition, it also demonstrates that differences in perception are detectable and measurable, especially when stimuli might evoke strong and differing emotional reactions. Nevertheless, further research is needed to understand the specific neural activation in more detail and should be extended to other animal production systems and generally to other aspects of sustainability.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of the University of Göttingen (Code: 32/12.17-Mehlhose, 05.02.2018). Informed consent was obtained from all subjects involved in the study.

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Article 3:

Signs of Warning: Do Health Warning Messages on Sweets Affect the Neural Prefrontal Cortex Activity?

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4.3 Signs of Warning: Do Health Warning Messages on Sweets Affect the Neural Prefrontal Cortex Activity?

Abstract

In the global attempt to combat rising obesity rates, the introduction of health warning messages on food products is discussed as one possible approach. However, the perception of graphical health warning messages in the food context and the possible impact that they may have, in particular at the neuronal level, have hardly been studied. Therefore, the aim of this explorative study was to examine consumers' reactions (measured as neuronal activity and subjective reporting) of two different types of graphical health warning messages on sweets compared to sweets without warning messages. One type used the red road traffic stop sign as graphical information ("Stop"), while the other one used shocking pictures ("Shock"), an approach similar to the images on cigarette packages. The neural response of 78 participants was examined with the neuroimaging technique functional near-infrared spectroscopy (fNIRS). Different hemodynamic responses in the orbitofrontal cortex (OFC), the frontopolar cortex (FOC), and the dorsolateral prefrontal cortex (dlPFC) were observed, regions which are associated with reward evaluation, social behavior consequences, and self-control. Further, the health warning messages were actively and emotionally remembered by the participants. These findings point to an interesting health information strategy, which should be explored and discussed further.

Keywords: fNIRS; graphical health warnings; health warning messages; prefrontal cortex; shocking images; warning label

Introduction

The number of overweight people worldwide has been rising continuously. In 2016, 39% of adults were considered overweight and 13% even obese (WHO, 2020). In 2017, 53% of all adults in Germany were overweight, 16% of them obese (DESTATIS, 2018). This is associated with an increased risk of developing non-communicable diseases such as diabetes, caries, and cardiovascular diseases (Guh et al., 2009). Far-reaching negative consequences for society and health systems might follow (Yates et al., 2017). In the global attempt to combat overweight, the introduction of health warning messages on food products is currently under discussion (Whelan, Morgan, Sherar, Orme, & Esliger, 2017).

Although the causes of overweight and obesity are complex and multifaceted, there is consensus that a decisive risk factor for overweight is a high energy, low micronutrient diet, which quickly leads to a positive energy imbalance (Swinburn, Caterson, Seidell, & James, 2004). A high energy density may be caused, for example, by a sugar-rich diet. In Germany, the daily consumption of added sugar is almost twice the quantity recommended by the WHO (BMEL, 2019; WHO, 2015). Exceeding these limits may sometimes happen intentionally, but it is more probable that people are not aware of their exposure to excessive quantities of sugar and the potential resulting health consequences (Cohen & Lesser, 2016).

The behavioral regulation of eating-related processes is a constant consideration between rewarding food stimuli around us, on the one hand, and self-regulating control processes, on the other hand (Alonso-Alonso et al., 2015). Through the omnipresence of tasty and often high-caloric food cues in our society, our desire to eat gets constantly and unconsciously stimulated, which affects our actual behavior more than we think (Inauen, Shrout, Bolger, Stadler, & Scholz, 2016). Food cues trigger areas in the brain that are responsible for reward and taste (Simmons, Martin, & Barsalou, 2005), inducing physiological reactions such as salivation (Keesman, Aarts, Vermeent, Häfner, & Papies, 2016), and easily lead to food-cravings and excessive consumption, even if there is no metabolic demand at that moment (Nederkoorn, Houben, Hofmann, Roefs, & Jansen, 2010; Nederkoorn, Smulders, & Jansen, 2000). The rewarding effects of food cues can be suppressed by the self-regulating control system, which makes it possible to resist appetizing food cues and thus to maintain personal long-term goals such as healthy eating or the avoidance of weight gain (Alonso-Alonso et al., 2015). However, it seems that food cues have different effects on overweight people than on people with normal weight, in the sense that obese people show increased reward activation (Pursey et al., 2014; Stoeckel et al., 2008) and decreased self-regulation activation in reaction to different food cues

(Batterink, Yokum, & Stice, 2010; Brooks, Cedernaes, & Schiöth, 2013). Obesity is also associated with automatic and stronger approach tendencies toward unhealthy food stimuli compared to those of normal-weight people (Mehl, Morys, Villringer, & Horstmann, 2019; Mehl, Mueller-Wieland, Mathar, & Horstmann, 2018). It seems that a poor ability to self-regulate eating behavior and habits and the automatic processes guiding unhealthy eating behavior may prevent people from resisting to rewarding food stimuli (Dohle, Diel, & Hofmann, 2017; Fürtjes et al., 2020). As such, food cues and the conditioned reactions of the body to these cues significantly contribute to eating behavior and weight gain (Boswell & Kober, 2016; Davidson, Jones, Roy, & Stevenson, 2019). Creating cues that help avoid undesired but automatic food-related behavior, such as health warning messages, might trigger a healthy behavior and strengthen self-control (Fürtjes et al., 2020).

Health warning messages or warning labels are expected to work in two ways: On the one hand, they address the cognitive system in providing information about the health consequences associated with consumption, which can intensify the intention to change this behavior and reduce purchase intentions for unhealthy food products (Adams, Hart, Gilmer, Lloyd-Richardson, & Alex Burton, 2015; Billich et al., 2018; Roberto, Wong, Musicus, & Hammond, 2016; VanEpps & Roberto, 2016). On the other hand, health warnings are expected to disrupt unconscious influences on food decisions, e.g., food cues and other external triggers, in priming a healthier food decision-making behavior (Rosenblatt et al., 2018a; Rosenblatt et al., 2018b).

The perception of food warning messages has not yet been sufficiently investigated, even though food warning messages already exist in some countries. The currently used ones, e.g., in Chile, are text-based only (Corvalán, Reyes, Garmendia, & Uauy, 2019), although studies from different contexts (e.g., snacks in general, tobacco, alcohol, or sugar-sweetened beverages) all came to the conclusion that graphical health warning messages seem to be more effective than text-based ones (Acton & Hammond, 2018; Bollard, Maubach, Walker, & Ni Mhurchu, 2016; Donnelly, Zatz, Svirsky, & John, 2018; Hammond, 2011; Mantzari, Vasiljevic, Turney, Pilling, & Marteau, 2018; Noar et al., 2016; Rosenblatt et al., 2018a; Stafford & Salmon, 2017; Sutton, Yang, & Cappella, 2018; Wigg & Stafford, 2016). Therefore, we examined graphical health warning messages in this study.

In order to get a better understanding of the possible effects health warning messages might have, it is of great interest to gain more insight into individual perceptions. Basically, one can distinguish two approaches: Direct approaches ask people directly about their perception and opinion concerning health warning messages. This helps to understand what people consciously think about it. However, direct questioning is insufficient when it comes to investigating the unconscious reactions and possible indirect effects of warnings as well, because a questionnaire often raises the problem of socially desirable response behavior and the fact that people are not aware of all their emotions, feelings, and so on. To this end, neuroimaging measurements can be a valuable tool, in the branch of indirect assessments. With their help, one can observe in which areas of the brain an increased neural activity can be measured in response to various stimuli. How food warning messages are perceived and the neural effects they have on consumers are not yet understood. So far, only one study examined the neural effects of warning messages in the context of food products: Rosenblatt et al. (2018b) found out, with the use of electroencephalography (EEG), that health warning messages enhanced dietary self-control through a reduction of the food cue reactivity. The EEG technique used in the above-mentioned study allows for a good temporal resolution of the brain activity data but not for a good spatial resolution. Other common neuroimaging studies use functional magnetic resonance imaging (fMRI), which is often limited to the study of a larger number of subjects because of its cost intensity and regarding the selection of the participants (Ariely & Berns, 2010). To tackle obesity and overweight research that involves large parts of society, it is crucial to examine more participants than the typically investigated 25–30 subjects in these studies. To overcome both aspects, we used a novel imaging process technology called functional near-infrared spectroscopy (fNIRS) in this study (Kopton & Kenning, 2014). It is more cost-effective than fMRI, and there are no restrictions regarding the selection of the participants. It therefore allows for an examination of the involved neural activity through hemodynamic responses in a large number of subjects (Pinti et al., 2018). This may be helpful in understanding the neural effects of food-related health warning messages in a quantitative manner. However, there are also limitations of fNIRS: There is poorer spatial resolution compared to fMRI due to the fact that fNIRS measurement is based on hemoglobin concentration changes measured through near-infrared light, whereas fMRI is measured through the changes in magnetic fields. In fNIRS, this leads to a low light penetration depth, which means that only the superficial areas of the brain can be measured, such as the prefrontal cortex. This also makes it more challenging to precisely localize the activated areas, as they are difficult to distinguish from one another. This might lead to results that are not as concrete or clearly interpretable to explain the underlying human behavior, which is why we combined the approach with a questionnaire about participants' health behavior, including a subjective reporting about the perception of the products with the health warning messages. Understanding the perception of health warning messages seems critical when there is a worldwide discussion about implementing such labels to pave the way for health strategies against non-communicable food-related diseases such as obesity and diabetes.

The purpose of this study was to examine consumers' perception of two different types of graphical health warning messages on sweets. One type used the red road traffic stop sign as graphical information, as it is a sign used in traffic known worldwide. Further, there already exist food warnings that have the form of stop signs, e.g., in Chile. The other one used shocking pictures (alternatingly one of a denture affected by caries and one of a foot with diabetic foot syndrome), an approach similar to that used in shocking images on cigarette packages. Both types of graphical messages were supplemented by textual information about caries or the diabetic foot syndrome. The aim of this paper was twofold: On the one hand, we wanted to investigate the neural responses of participants with fNIRS as measured by hemodynamic activities in prefrontal brain regions during the perception of these health warning messages, in order to explore which brain areas and related psychological processes might be important to enhance the understanding and effectiveness of graphical warning signs. On the other hand, we aimed to compare how the two types of warning messages were perceived by the participants, which we did by analyzing their subjective reporting in a direct assessment and by contrasting them with the fNIRS measurements. Due to the novelty of fNIRS as an imaging technology for examining consumer behavior, this study is of an explorative character, further aiming to validate this methodology against other elements of socio-empirical research.

Materials and Methods

Participants

A hundred and three German students were randomly recruited to take part in the study. All of them gave their written consent to participate in this study and received monetary compensation at the end of the study (5€). They were all informed about the test procedure, the fNIRS methodology, and that they could withdraw from the study at any time without consequences. The study was conducted in accordance with the Declaration of Helsinki and with the principles of the ICC/ESOMAR Code. The procedure and the use of fNIRS were approved by the Ethical Committee of the University. Twenty-five participants had to be excluded due to poor data quality (22 participants) or errors during data recording (three participants). Data analysis was hence continued with 78 participants. Of these, 44 were female and 34 of them male. The mean age was 25.4 years, with ages ranging from 18 to 39. The average body mass index (BMI) was 23.4 and ranged from a minimum of 15.8 to a maximum of 37.5. For further analysis, we divided the participants into two groups according to their BMI. The High_BMI group consisted of 22 persons, 10 men and 12 women, who had a BMI classified as overweight or obese (cut-off value men: 25, cut-off value women: 24). The upper and lower limits of the BMI value classes are slightly higher for men than for women (the WHO recommends 25 for men and women) because men generally have a higher proportion of muscle mass in total body mass than women. Their mean age was 26 years. We checked for significant differences of age between the two groups but found no differences. The Normal_BMI group consisted of 56 participants, of which 24 were men and 32 were women, and the mean age of this group was 25.1 years. The High_BMI group was considerably smaller, since we could not explicitly recruit the subjects based on their body weight/BMI due to ethical reasons.

Stimuli

To create the health warning messages, we used two different types of graphical symbols: First, we used the red traffic road stop sign as a graphical warning symbol ("Stop"). Then, we used shocking images as graphical warning symbols, similar to those on tobacco packages ("Shock"). For this, we used a picture of a denture affected by caries and a second picture with a foot affected by diabetic foot syndrome. We selected these diseases to illustrate the effects of caries and diabetes, because they are well-known secondary diseases of excessive sugar consumption (Delli Bovi, Di Michele, Laino, & Vajro, 2017).

Further, we used two different types of textual information to combine them with the graphical symbols: one provided information about caries and the other one about the diabetic foot syndrome. The information about caries read (translated from the German original): *"Caries (lat. rottenness, morass) is a multifactorial dental disease that is promoted by sugar"*. Similarly, the information about the diabetic foot syndrome read: *"Excessive sugar consumption leads to tooth decay, obesity, and diabetes. The diabetic foot is a common secondary disease of diabetes mellitus"*.

So, in total, four different health warning messages were created, each consisting of a graphical symbol and the appropriate textual information next to it. This resulted in a 2 ("Stop"/"Shock") × 2 (caries/diabetic foot syndrome) factorial design. The graphical and textual warnings are shown in Figure 1.

Figure 1: Four different health warning messages were created. For the “Stop” examination condition, a stop sign was used (two pictures on the left). For the “Shock” examination condition, two shocking pictures (one of a denture affected by caries and one of a foot with diabetic foot syndrome) were used. The textual information informed about caries and the diabetic foot syndrome and was identical for both types of warning messages.

The warning messages were printed on small stickers (21 × 76 mm) and then attached onto real sweets products. We used eight different sweets products of the type gummy bears, chocolate bars, and cookies. Each product was labeled once with each warning message. In total, this resulted in 32 differently labeled sweets (four different graphical warnings each on eight different products). All products were bought in a typical German grocery store, and all items were branded products to ensure that they were familiar to the participants. Our aim was to present the products as realistically as possible. Therefore, pictures of all products were then taken to present them as visual stimuli to the participants. The images were edited with the help of the image-editing program Paint 3D but only to remove shadows or reflections.

To conserve statistical power, the examination conditions of the experimental design differed only between the two different graphical types of health warning messages. This means that all textual health warning variants (caries/diabetic foot syndrome) were grouped together, resulting in a “Stop” condition and a “Shock” condition. This resulted in 16 different pictures for each of the two experimental conditions. Additionally, we used seven other unlabeled sweet products to have a wider range of products for a neutral control condition, resulting in 15 pictures for the control condition (the same eight different products from the examination condition unlabeled, plus seven additional products, also unlabeled).

Experimental Design

The fNIRS experiment consisted of a block design with two experimental conditions (“Stop” condition and “Shock” condition) and one control condition (“Neutral” condition). In total, there were three different blocks with five runs per block. The order of the blocks was randomized. One block consisted of four randomly chosen pictures from the respective condition. Each picture was shown for 5 s, resulting in a duration of 20 s per block, followed by a pause of 25 s, which was represented by a small cross on the screen. The presentation started and ended with instructions, which were shown for 9 s each. This lasted for a total experimental duration of 11.5 min. The precise instructions to the participants were as follows: "Please look at the products carefully and pay attention to noticeable differences." The experimental design can be seen in Figure 2.

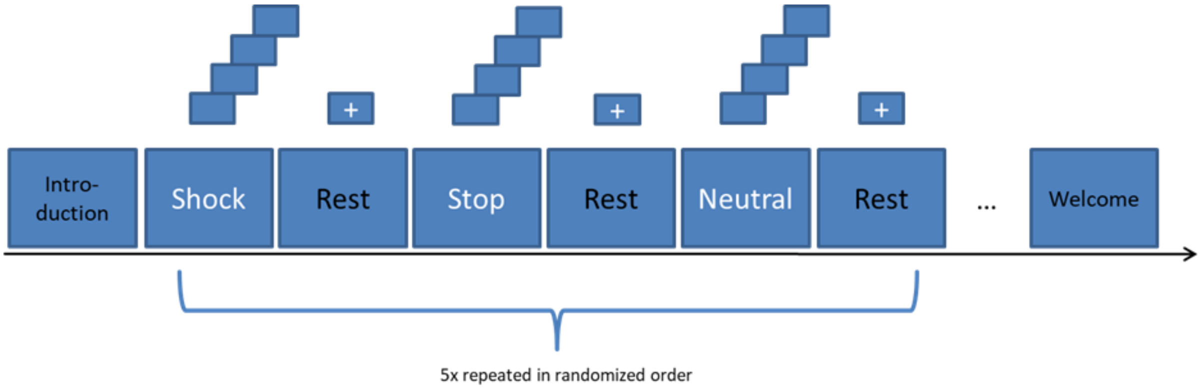

Figure 2: Experimental Design of the fNIRS experiment. A block design with three experimental conditions ("Shock", "Stop", and "Neutral") was used. The order of the trials was randomized.

Study Procedure

Each participant completed a single experimental fNIRS session, followed by a questionnaire. The study took place in a room specifically set up for the experiment, which contained no furniture or wall decoration other than a table and chair for the subject and the experiment leader. It was also ensured that no direct light fell on the fNIRS setup. The fNIRS experiment and the questionnaire were computer-based and were presented to the subjects on a 19.4-inch computer screen. First, the participants were informed about the basic procedure of the study and had the opportunity to ask questions before agreeing to participate. They were then fitted with the fNIRS headband and asked to sit as still as possible and to avoid strong head movements for the duration of the experiment. We then started the presentation of the stimuli. After completing the fNIRS part of the experiment, the participants' headband was removed again, and they were asked to respond to the questionnaire. The stimulus presentation and the experimental control were carried out with the help of the program Presentation (version 20.3.), by the company NeuroBehavioralSystems (NBS). The survey data was collected through the online survey software program Unipark, from Questback.

fNIRS Measurement and Data Analysis

fNIRS visualizes brain activity through the ability of hemoglobin to absorb light. Sources of near-infrared light penetrating the human tissue are used to measure the differences of cerebral oxygenated hemoglobin (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb) at certain times (Ferrari & Quaresima, 2012). We can therefore draw conclusions about the neural activity beneath the surface of the brain: An increase in metabolic demand for oxygen during a mental task leads to a stronger cerebral blood flow in this area, to fulfill the demand. This so-called “neurovascular coupling” principle is quantified in fNIRS through the measurement of the absorption rate of the different colors of blood (brighter red = oxygenated blood, darker red = deoxygenated blood) (Pinti et al., 2018). As such, the mechanism is similar to the principle used in fMRI measurements (BOLD signal), which allows the fNIRS signal to be compared to the fMRI signal (Masataka, Perlovsky, & Hiraki, 2015). The advantage of fNIRS, however, is that due to its simple setup, it is much more cost-effective and mobile than fMRI (Meyerding & Mehlhose, 2020). As the fNIRS setup is non-invasive and only works with near-infrared light, there are no safety concerns, which makes fNIRS suitable for all types of participants and permits an analysis of larger sample sizes (Pinti et al., 2018). We used a mobile fNIRS device (NIRSport, NIRx Medical Technologies, Berlin, Germany) for the measurements in this study. This is a two-wavelength (760 and 850 nm) continuous wave system that collects data in parallel at a sampling rate of 7.81 Hz. On a neoprene headband, eight light sources and seven light detectors are placed at a distance of three centimeters of each other. This results in 22 measurement channels covering parts of the prefrontal cortex. Specifically, it covers parts of Brodmann Area 9, 10, 11, and 46, and thus parts of the orbitofrontal (OFC), the dorsolateral (dlPFC), and the frontopolar prefrontal cortex (FPC). A schematic representation of the topographical layout (left) and the coverage on a brain map (right) are shown in Figure 3.

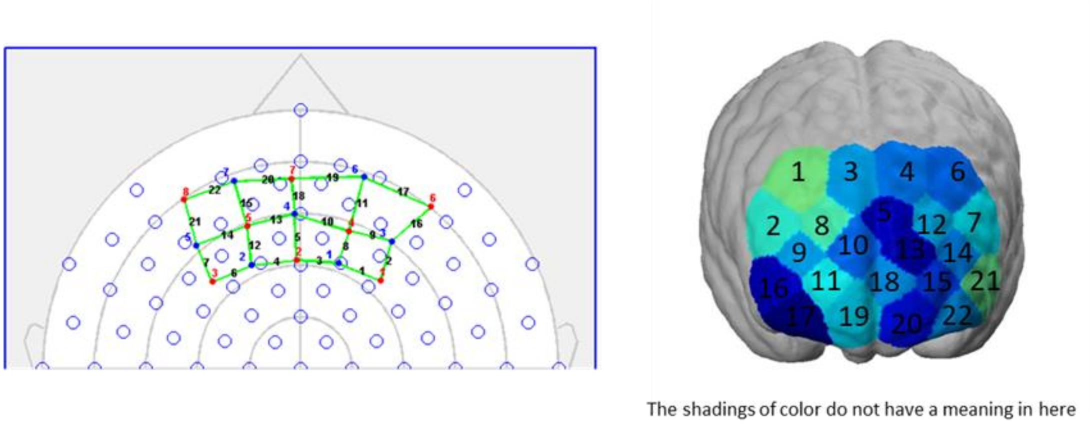

Figure 3: *Left:* Topographical layout of the NIRx headband. The red numbers (1–8) point out the placement of the light sources, and the blue numbers (1–7) the placement of the light detectors. One source and one detector result in one measurement channel, visualized through the black channel numbers (1–22). The reference points refer to the EEG 10–20 system. *Right:* The coverage of the headband is shown on the ICBM 152 head model. The color shadings do not have any meaning here.

The headband was placed on the forehead of each participant according to the craniometric points of the head. We used the nasion of each participant as a measurement point to place the source number 7 in the same place for each participant, and thus created comparability between the participants. NIRStar software package (version 15.0) was used to check for signal quality and data collection.

Before analyzing the data, we performed several preprocessing steps of the raw optical data: First, we verified the data quality of every individual dataset. We compared the signal-to-noise ratio of each channel with the coefficient of variation (CV). Channels with a value higher than the threshold of 7.5 (default value) were marked as bad and excluded from the subsequent analysis. Participants with half of all or more bad channels were excluded from further analysis. Twenty-two participants were completely removed for this reason. We then band-pass filtered the data (of 0.01–0.2 Hz) to smooth out both very rapid and very slow fluctuations. Strong motion artifacts and discontinuities were removed manually as well. The raw optical density signals were then modified into hemoglobin concentration changes through a modified Beer–Lambert law. In terms of parameters, the wavelength was specified to values of 760 and 850 nanometers, and the pathlength factors were set to 7.25 and 6.38. Data analysis was continued only with oxy-Hb, as this has been shown to correlate more strongly with the cerebral blood flow (Hoshi, Kobayashi, & Tamura, 2001). The preprocessing of the raw optical data as well as the analysis of the neural data were performed with the NIRx Software package nirsLAB version 2019.4.

We analyzed the hemodynamic-state time series of the different channels during the experimental conditions with the help of a General Linear Model (GLM) for every participant and each block. We modeled the parameters of the single experimental trials grouped together, resulting in three event-related regressors and the constant error term ($Yj = xj1\beta1 + xj2\beta2 + xj3\beta3 + \varepsilon j$). To model the onsets of neural activity, we used the hemodynamic response function. T-contrasts were calculated for the main effects of the single conditions and to compare the experimental conditions with the control condition (Stop vs. Neutral, Shock vs. Neutral). These contrasts were used to generate statistical parametric maps (SPM) for the whole group of participants (between-subject level). Further, we contrasted two subgroups of the sample based on their physical constitution (measured with BMI) in relation to the experimental conditions (HighBMI_Shock vs. NormalBMI_Shock, HighBMI_Stop vs. NormalBMI_Stop, NormalBMI_Shock vs. HighBMI_Shock, NormalBMI_Stop vs. HighBMI_Shock). The activation threshold was set at least to $p < 0.1$, and the thresholded brain activation maps were then plotted on the standardized head model (ICBM-152), which is included in the nirsLAB software. We matched the fNIRS channels with the 10–20 system EEG reference points and mapped them according to (Jurcak, Tsuzuki, & Dan, 2007) and with the help of the fOLD toolbox (v2.2) for information about the activated anatomical areas of the brain. These refer to Brodmann Areas and the brain regions associated with them. Multiple comparison corrections were performed using the false discovery rate (FDR) method.

Direct Assessment (Questionnaire)

Immediately after the end of the fNIRS experiment, the participants were asked to fill in a questionnaire. The first two questions were open questions, where we aimed to determine whether the participants recognized the health warning messages on the products, and we asked if they believed that the shown products might influence their purchase behavior and why. With the first question, we aimed to find out whether the participants recognized the health warning messages at all and whether they paid attention to them. The second question aimed to identify their beliefs and intentions concerning the possible effectiveness of the health warning messages, i.e., the influence on their purchase behavior. Furthermore, the questionnaire contained general questions about the food, sleep, and movement behavior of the participants. The evaluation of the open questions was based on (Mayring, 2010). We evaluated the answers of all subjects (excluding one who did not answer this question) who participated in the fNIRS experiment (resulting in $n = 102$) and not only those who had valid data for the fNIRS analysis. This allowed us to compare the impressions about the general perception of health warning messages.

Results

We observed different hemodynamic responses regarding the main effects of the experimental conditions, the two different graphical health warning messages compared to the control condition, and the subgroups of the sample based on their physical constitution (BMI). The results of the main effects are reported with a significance level of $p \leq 0.05$, and those of the experimental conditions compared to the control conditions with $p \leq 0.1$. This was done because our conditions did not differ significantly, since we used for both experimental conditions the same product pictures, and only the health warning messages differed, not leading to very strong reactions. The results indicate increased neural activity in brain regions of the prefrontal cortex—among others, of the orbitofrontal cortex (OFC), the frontopolar cortex (FOC), and the dorsolateral prefrontal cortex (dlPFC).

Main Effects of the Experimental Conditions

The main effects of the experimental conditions can be associated with the following results, which are significant on a level of $p \leq 0.05$:

The "Neutral" condition significantly decreased neural activity in parts of the **dlPFC** (*channel 3*: $t(78) = -3.56$, $p \leq 0.001$, $d = 0.8$; *channel 4*: $t(78) = -2.23$, $p \leq 0.05$, $d = 0.5$; *channel 5*: $t(78) = -2.74$, $p \leq 0.01$, $d = 0.62$; *channel 6*: $t(78) = -2.79$, $p \leq 0.01$, $d = 0.63$; *channel 9*: $t(78) = -2.63$, $p \leq 0.05$, $d = 0.59$; *channel 14*: $t(78) = -3.22$, $p \leq 0.01$, $d = 0.72$; *channel 21*: $t(78) = -3.23$, $p \leq 0.01$, $d = 0.73$), the **OFC** (*channel 17*: $t(78) = -2.45$, $p \leq 0.05$, $d = 0.55$; *channel 19*: $t(78) = -4.14$, $p \leq 0.001$, $d = 0.90$; *channel 20*: $t(78) = -3.78$, $p \leq 0.001$, $d = 0.85$; *channel 22*: $t(78) = -4.51$, $p \leq 0.001$, $d = 1.0$), and the **FPC** (*channel 10*: $t(78) = -2.43$, $p \leq 0.05$, $d = 0.55$; *channel 11:* $t(78) = -2.96$, $p \leq 0.01$, $d = 0.67$; *channel 15:* $t(78) = -3.87$, $p \leq 0.001$, $d = 0.87$; *channel 18*: $t(78) = -4.22$, $p \leq 0.001$, $d = 0.95$) (see Figure 4, left brain).

The "Stop" condition significantly decreased neural activity in parts of the **dlPFC** (*channel 3:* $t(78) = -2.06$, $p \leq 0.05$, $d = 0.46$; *channel 14*: $t(78) = -2.12$, $p \leq 0.05$, $d = 0.48$), the **OFC** (*channel 20*: $t(78) = -2.08$, $p \leq 0.05$, $d = 0.47$; *channel 22*: $t(78) = -2.2$, $p \leq 0.05$, $d = 0.5$), and the **FPC** (*channel 15*: $t(78) = -2.22$, $p \leq 0.05$, $d = 0.5$; *channel 18:* $t(78) = -3.4$, $p \leq 0.01$, $d = 0.7$) (see Figure 4, brain in the middle).

The "Shock" condition significantly also decreased neural activity in parts of the **dlPFC** (*channel 3:* $t(78) = -2.15$, $p \leq 0.05$, $d = 0.48$; *channel 14*: $t(78) = -2.28$, $p \leq 0.05$, $d = 0.51$), the **FPC** (*channel 10:* $t(78) = -2.06$, $p \leq 0.05$, $d = 0.46$, *channel 18*: $t(78) = -3.53$, $p \leq 0.05$, $d = 0.79$), and the **OFC** (*channel 17:* $t(78) = -2.0$ $p \leq 0.05$, $d = 0.45$; *channel 19*: $t(78) = -3.71$, p

≤ 0.001, d = 0.84; *channel 20*: t(78) = −3.05, p ≤ 0.01, d = 0.69; *channel 22*: t(78) = −3.38, p ≤ 0.01, d = 0.76) (see Figure 4, right brain).

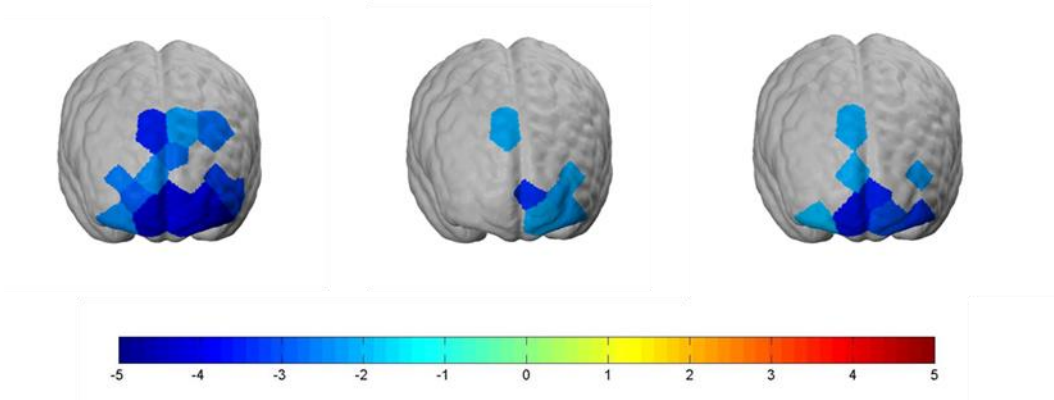

Figure 4: Significantly decreased neural prefrontal cortex activation for the main effects of the "Neutral" (left brain), "Stop" (middle brain), and "Shock" condition (right brain). Activation threshold set to $p < 0.05$.

Experimental Conditions Compared to Control Condition

Related to all participants, the contrasts of the experimental conditions ("Stop" and "Shock") compared to the control condition ("Neutral") can be associated with the following results, which are all significant on a liberal significance level of at least p ≤ 0.1.

The "Stop" condition significantly increased bilateral neural activity in the OFC and the FPC. More specifically, the "Stop" condition led to a significantly increased bilateral neural activation in *channel 22*: t(78) = 1.93, p ≤ 0.1, d = 0.437; *channel 21*: t(78) = 1.69, p ≤ 0.1, d = 0.382; *channel 19:* t(78) = 1.97, p ≤ 0.1, d = 0.315, and *channel 17:* t(78) = 1.71, p ≤ 0.1, d = 0.446, when compared to the "Neutral" condition (see Figure 5). However, the "Shock" condition, when compared to the "Neutral" condition, did not show increased neural activity in the OFC but led to a significantly increased lateral neural activation in the FPC, more precisely in *channel 15*: t(78) = 1.757, p ≤ 0.1, d = 0.398 (see Figure 6). In order to talk about differences between the two types of health warnings, we also contrasted them directly. However, we did not find significant results for the interaction of the "Stop" with the "Shock" condition compared to the "Neutral" one.

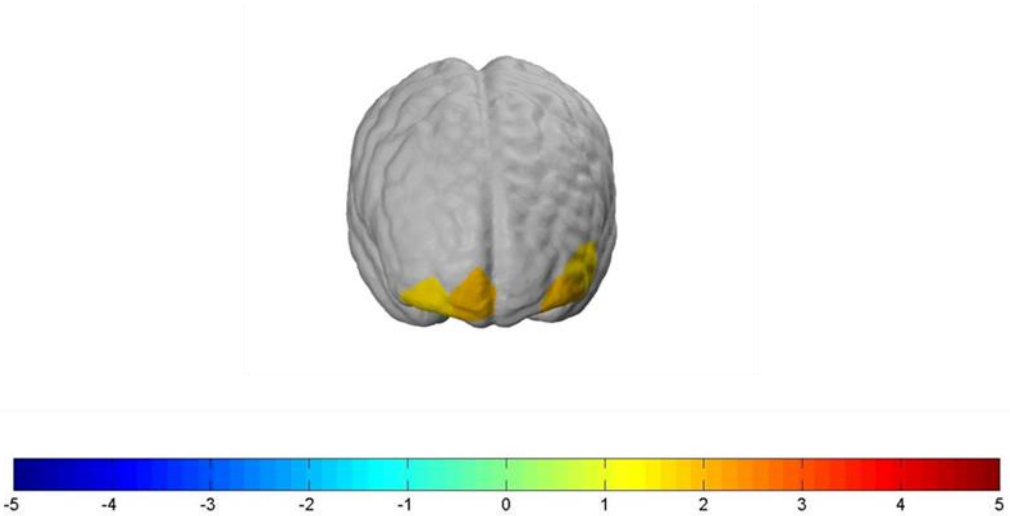

Figure 5: Significantly increased neural prefrontal cortex activation for the contrast between the "Stop" condition versus the "Neutral" condition: *channel 22*: $t(78) = 1.93$, $p \leq 0.1$, $d = 0.437$; *channel 21*: $t(78) = 1.69$, $p \leq 0.1$, $d = 0.382$; *channel 19*: t(78) = 1. 97, $p \leq 0.1$, $d = 0.315$, and *channel 17*: $t(78) = 1.71$, $p \leq 0.1$, $d = 0.446$. The activation threshold was set to $p < 0.1$.

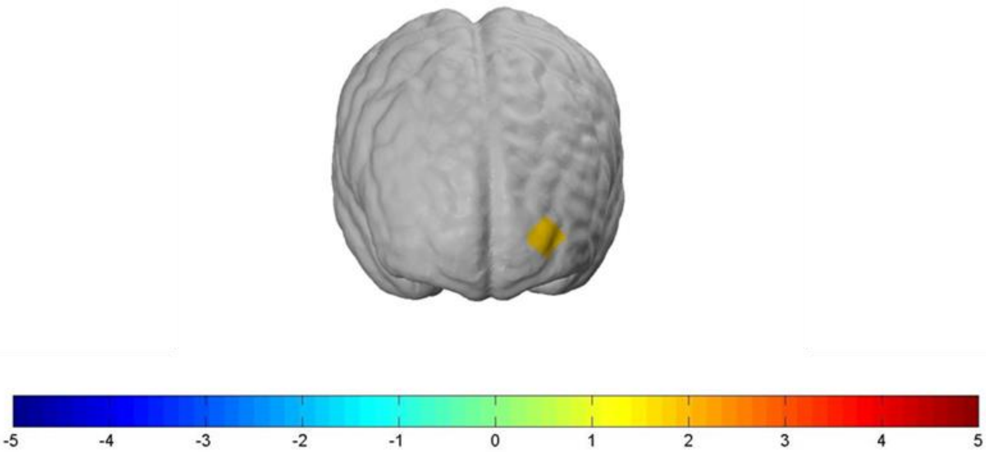

Figure 6: Significantly increased neural prefrontal cortex activation for the contrast between the "Shock" condition versus the "Neutral" condition: *channel 15*: $t(78) = 1.757$, $p \leq 0.1$, $d = 0.398$. The activation threshold was set to $p < 0.1$.

Group Comparison of High vs. Normal BMI

According to the physical constitution of the participants, we contrasted one group with a normal BMI (n = 56) (NormalBMI) and the corresponding hemodynamic response to the experimental conditions with another group with a high BMI (n = 22) (HighBMI) and their neural activity in relation to the experimental conditions. This achieved the following results, which are all significant on a liberal significance level of at least $p \leq 0.1$:

For the NormalBMI group, increased bilateral neural activity in parts of the dlPFC compared to the HighBMI group was measured when exposed to the “Stop” condition. More specifically, this held true for *channel 3*: $t(78) = 2.19$, $p \leq 0.05$, $d = 0.53$ and *channel 4*: $t(78) = 1.90$, $p \leq 0.1$, $d = 0.26$. Further, we also measured increased lateral neural activity in the dlPFC when exposed to the “Shock” condition. This held true for *channel 3*: $t(78) = 1.90$, $p \leq 0.1$, $d = 0.43$ (see Figure 7). We found no significant differences between the two groups when being exposed to the control condition.

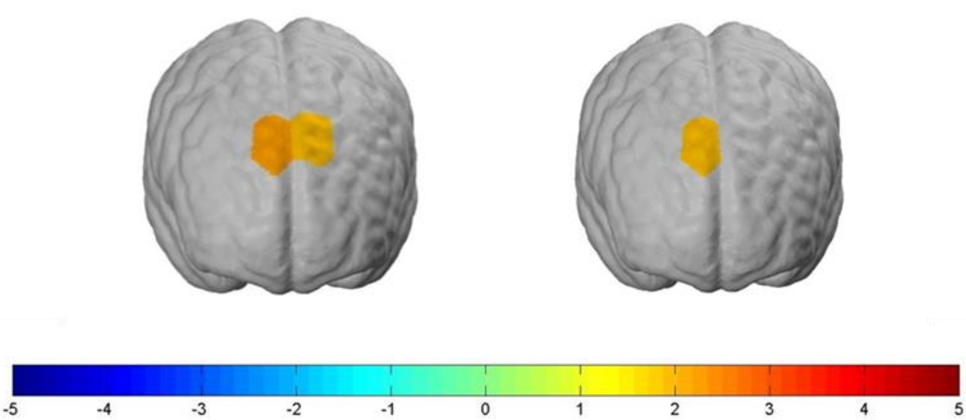

Figure 7: Contrast of the NormalBMI group (n = 56) with the HighBMI group (n = 22) for the two experimental conditions. The participants with a normal BMI showed significantly increased prefrontal cortex activation compared to the ones with a high BMI in both experimental conditions. *Left brain*: For the NormalBMI group, neural activity in the dlPFC increased when exposed to the “Stop” condition. *Right brain*: For the NormalBMI group, neural activity in the dlPFC increased when exposed to the “Shock” condition.

Direct Assessment (Questionnaire)

We directly asked participants what they focused their attention on during the experiment. The exact question was: “What did you look for?” Altogether, we classified 253 statements and assigned them to four different categories: statements related to the warning messages (100 counts/39.53%), to the products or individual product features (78 counts/30.83%), to the packaging of the products (57 counts/22.53%), and to the change of the focus (18 counts/7.11%). Interestingly, the majority of the participants actively perceived and remembered the health warnings. 75.7% of the participants mentioned that, amongst other categories, they actively paid attention to the health warnings. The other 24.3% provided statements of the other categories only.

Further, we asked whether the participants thought that the products they saw would influence their purchase behavior and why. The exact question was: “What do you think: would the shown products have an effect on your buying behavior? Why?” For this question, we classified 234 statements and assigned them to four different categories: statements related to the effectiveness of the health warnings in general (108 counts/46.15%), statements that mentioned “No influence on my behavior, because…” (66 counts/28.21%), statements that mentioned “Yes, it would influence my behavior, because…” (44 counts/18.8%), and statements related to the influence of the products itself (12 counts/5.13%).

Discussion

The main focus of this study was on neural prefrontal cortex activation caused by the perception of two different types of health warning messages on sweet snack products.

Our results show that both for the “Stop” condition and the “Shock” condition, participants’ neuronal activity increased significantly compared to the “Neutral” control condition. This is in line with a number of other neuroimaging studies that also found an increase in neuronal activity in relation to graphical and text-based warnings, mostly in the context of smoking behavior (Chua et al., 2011; Dinh-Williams, Mendrek, Bourque, & Potvin, 2014; Newman-Norlund et al., 2014; Wang, Lowen, Romer, Giorno, & Langleben, 2015; Whelan et al., 2017). To the best of our knowledge, in the context of food products, only one study has examined the neural signals of health warning messages thus far. It found a reduced neural reaction to these messages, which was explained by an automatic appetite-control-regulation of the participants (Rosenblatt et al., 2018b). However, a comparison with our results is only possible to a limited extent, since EEG was used in the other study, an imaging procedure based on the electrical activity of the brain and not based on the metabolic activity of the brain, as is the case with fNIRS or fMRI measurements.

Our results revealed, furthermore, that the “Stop” condition significantly increased activation in parts of the OFC. The OFC plays a crucial role in representing and evaluating positive and negative reinforcers and is considered part of the reward region of the brain (Kringelbach, 2005; Peters & Büchel, 2010). As such, it is associated with many cognitive processes in the context of integrating sensory information to subsequent behavior (Blechert, Klackl, Miedl, & Wilhelm, 2016; Gottfried, O'Doherty, & Dolan, 2003; Kringelbach, 2004; Kringelbach, 2005; Kringelbach & Rolls, 2004; O'Doherty, Deichmann, Critchley, & Dolan, 2002; Peters & Büchel, 2010; van der Laan, de Ridder, Viergever, & Smeets, 2011; Zald, 2009). Our results are in line with another study, which found increased activation in the OFC for aversive smoking images versus control images (Dinh-Williams et al., 2014). The authors explained their results based on the fact that smoker experienced an arousing and unpleasant emotional response when attending to the negative value of their consumption and therefore try to modulate or suppress these feelings. Hollmann et al. (2012) asked participants to regulate their desire for food and thereby evaluated the long-term consequences of eating the food for society and health. They found an increased hemodynamic response in this area as well and interpreted it as an evaluation of the negative consequences following of the absence of a reward. It is therefore conceivable that these processes are also part of the processing of health warning messages. Our results revealed, further, a significant increase in activation in one channel of the frontopolar cortex (BA 10) for the “Shock” as well as for the “Stop” condition when compared to the neutral condition. This is the only significant neural activation which we found for the “Shock” condition. Basically, this is in line with the results of, e.g., Chua et al. (2009), who found activation in the rostral medial prefrontal cortex (BA 10) for text-based health warning messages. The FPC plays a key role in future thinking and planning and has been associated with emotional, cognitive, and social processes, and especially with the long-term consequences of social behavior as well as feelings of guilt. We can only speculate at this point, but as almost half of all answers of the direct approach were statements related to the effectiveness of the health warnings in general, it is conceivable that the shock warnings in particular are impressive reminders of the consequences of unhealthy behavior or might even cause feelings of guilt.

Further, our results showed that participants with a normal BMI had significantly increased neural activity in the dlPFC in both experimental conditions compared to participants with a higher BMI, who had a significant decrease in neural activity. The dlPFC is part of the prefrontal control region and is, in this context, associated with self-regulation and self-control (Han, Boachie, Garcia-Garcia, Michaud, & Dagher, 2018; Hare, Camerer, & Rangel, 2009; Hare, Malmaud, & Rangel, 2011; Kober et al., 2010), weighting the immediate rewarding values, e.g., of food cues, against the expected personal long-term consequences (positive or negative) resulting from them (Yokum & Stice, 2013). This shows an increased hemodynamic response when regulating processes to suppress food or cigarette cravings (Do & Galván, 2015; Hare et al., 2009; Hollmann et al., 2012). Our results are therefore in line with, e.g., the study by Hollmann et al. (2012), which observed significantly increased neural responses in dlPFC during the active regulation of the desire for unhealthy food. However, Kober et al. (2010) also showed that a cognitive regulation of food and cigarette cravings increased neural activity in the dlPFC. These effects are explained by cognitive strategies that help diminish the craving by focusing on the long-term consequences of smoking. At the same time, it has been shown that a higher BMI is related to reduced neural activation in response to food images in the brain regions that are assigned to inhibitory control and self-control—i.e., the dlPFC, among others (Batterink et al., 2010; Han et al., 2018). At this point we can only speculate, but one could think (and this should be investigated further) that the individuals with normal BMI, who showed increased neural activity, used the warning messages on the sweets to solve the conflict between external information (health warnings) and internal desire (tasty sweets) and regulated their desire better or more than the group with a high BMI.

Red nutrition labeling was thought to decrease the value of a product due to the negative information associated with the product, which was the case for the "Stop" condition (Enax, Hu, Trautner, & Weber, 2015). To date, there has only been one other study that also used a stop sign (in black). The results did not show one of two different labels performing better than the other one in reducing the willingness to purchase for products that are high in sugar. The authors concluded that, in general, there is a high potential for some kind of front-of-package labels to reduce the sugar consumption, but the type of label might not be that important (Ang, Agrawal, & Finkelstein, 2019); however, coloring may be a helpful guidance for consumers. This can be underlined by the reports of our participants, which showed that the majority of individuals actively perceived and remembered the health warning messages. Almost half of the statements we classified were about the perceived or associated general effect and effectiveness of the warnings and what the test persons felt when looking at them. This shows that the warning messages were able to provoke emotional reactions among the participants, which might be important to induce behavioral changes. However, whether these would be positive reactions (e.g., reduction of sugar content) or negative effects (e.g., reactance effects, habituation effects) cannot be conclusively determined at this time and should be investigated further.

We want to mention, further, that our study is missing additional behavioral measurements that would have allowed us to really validate the fNIRS findings with particular psychological processes, such as reward evaluation, social behavior consequences, or self-control. As such, we can only make first suggestions and state the mental processes that are related to these brain areas and that might be of interest for further research concerning the processing of health warning messages. Especially in areas such as neuroeconomic and consumer neuroscience, mental processes and underlying brain functions are much less understood. We aim to start to evolve into consumer behavior and consumers' neural actions, which is why our results should be seen as first explorative insights on what might eventually be possible and what other studies can build upon. This might help to shed some light on the novel measurement technology fNIRS in the context of consumer behavior.

Strengths and Limitations

This study has a number of strengths and thereby adds important value to the worldwide discussion about obesity prevention strategies. First of all, the measurement with fNIRS allowed us to examine a considerably larger number of persons, and thus considerably increased the generalizability of the neuroimaging results. In this case, we used photos of real products as stimuli and added graphical health warning messages that were adapted and placed in such a way that a realistic representation of the products remained. It should also be stressed that the recruited subjects were both normal-weight and overweight individuals, which increases the relevance of the results significantly, as potential preventive effects of warnings would probably have an effect on both groups—which is why it is crucial to investigate both groups at the same time.

This study also had limitations: Our trial number, with five runs and five pictures, was quite small. This might be one of the reasons why we did not detect strong effects in our data. To improve the reliability of the fNIRS signal, one could have increased the trial numbers, but we wanted to prevent the subjects' attention from drifting away. Another shortcoming is that the headband we used cannot be fastened to the head as firmly and stably as, for example, a cap for the whole head, which can also be fastened under the subject's chin. Therefore, for participants with thicker or darker hair, that absorbs more light, poor data quality can occur more quickly. This might explain the relatively high number of test persons that had to be excluded from our sample due to poor channel quality. Nevertheless, due to ethical and random sampling reasons, we did not screen people for their hair color. We also did not screen the participants for any eating disorders, which might have affected participants' reactions to the food pictures. However, only two participants of our sample can be classified as underweight; only one reported a BMI lower than 16; so, if this affected the data, it did so only to very small parts.

Another limitation that needs to be considered is that we used a liberal significant threshold of 10% for the contrasts between the experimental and the control conditions. This was done because our conditions did not differ extremely, since we used the same product pictures for both experimental conditions and only the health warning messages differed, not leading to very strong reactions. However, in order to actually talk about, and give guidance for future studies in regard to, the differences between health warning label conditions, the interaction contrasts between the experimental condition and control condition are the really interesting ones, which is why we reported the results in this way.

All stickers were adjusted on "real-life" products to simulate real-life situations. Within, the sizes of the letters differed marginally but according to real market conditions. We used fixed margins for the text box, large enough for the text information to be easy to read on the product pictures. We did not control for this, so this could have affected the efficacy of the stickers.

Conclusions

This paper highlights the neural responses of participants during the perception of different health warning messages, as well as their differing effects on normal-weight and overweight people, measured with the innovative neuroimaging technology fNIRS. Our findings contribute to the growing body of literature about the potential of health warning messages as a possible intervention strategy to combat overweight. Stop signs and shocking images as additional graphical information for textual health warning messages were actively and emotionally remembered by the participants and seem to lead to increases in neural activation in the OFC, FPC, and dlPFC regions of the prefrontal cortex. Nevertheless, we cannot determine which effect they would have. Therefore, we see our results as a starting point for further research, especially concerning the effectiveness of a "Stop" symbol in reducing sugar consumption, because the symbol is widely known and thus already strongly anchored in people's consciousness, but also concerning a further validation of fNIRS methodology against other elements of socio-empirical research in order to be able to connect the imaging findings to particular mental processes.

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Article 4:

Sensory Measurements of Taste: Aiming to Visualize Sensory Differences in Taste Perception by Consumers—An Experiential fNIRS Approach

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4.4 Sensory Measurements of Taste: Aiming to Visualize Sensory Differences in Taste Perception by Consumers—An Experiential fNIRS Approach

Abstract

Especially for long-term acceptance, taste is the most important determinant to assess consumer habitual uptake of food products. Monitoring neuronal processes is expected to provide insights for hedonic preferences. The aims of this study are: (1) to find out whether and how two different taste nuances are reflected in the neuronal data and (2) to assess whether preference of two plant-based milk alternatives can be detected. In total 91 subjects underwent a tasting experiment with two different plant-based milks (oat and almond milk) and a water sample (neutral taste), while neuronal data was recorded. A relative decrease in oxygenated hemoglobin (oxyHb) during tasting was detected in parts of the dorsolateral prefrontal cortex (dlPFC). However, no differences were detected between the three samples, although the overall liking on hedonic scales differed. Hence, the assessment may have visualized the taste process activation, but could not assign a differentiated hedonic preference evaluation. For the latter a stronger polarity may be needed.

Keywords: fNIRS; prefrontal cortex; plant-based milk; consumer neuroscience; consumer acceptance

Introduction

The taste of a food product influences consumers perception and is one of the most important aspects considered in food decision situations (Mäkinen, Wanhalinna, Zannini, & Arendt, 2016; McClements, Newman, & McClements, 2019). However, consumers' perception of taste is a complex phenomenon that is not yet fully understood, also because it is processed through a multicomplex system of sensory analysis (Stasi et al.,2018). Moreover, approximately 95% of all food choice processes occur unconsciously (Zaltmann, 2003) and are influenced by factors beyond the sensory properties of the food (e.g., taste, smell). For example, our subconscious associates certain foods with pleasure and happiness and certain others with fear (Stasi et al., 2018).

To understand consumer decision-making in food choices, it may be useful to view consumer decisions from a multidisciplinary perspective. Consumer studies, which aim to locate consumers in their real environments, may benefit from experiential sensory and neuroeconomic behavioral research (Plassmann, Venkatraman, Huettel, & Yoon, 2015). Sensory science makes extensive use of techniques or principles that contribute to the understanding of food characteristics that influence hedonic evaluation (Lawless & Heymann, 2010). Consumer neuroscience aims to adapt methods and theories from neuroscience, in combination with behavioral theories to focus on the understanding of consumer behavior and its individual preferences e.g., through sensory ratings (Plassmann, Ramsøy, & Milosavljevic, 2012). The understanding may be important to better interpret the preference evaluation, because processing of taste on a neuronal level is not yet clear. As such, the aim of this study was to bring together three disciplines to enhance experiential studies in the context of neuronal and sensory measurement of taste.

A number of studies have already been published on the location and extent of brain activity in response to the taste and aroma of various foods with positive and negative hedonic properties (Araujo, Rolls, Kringelbach, McGlone, & Phillips, 2003; Critchley & Rolls, 1996; Hare, O'Doherty, Camerer, Schultz, & Rangel, 2008; McCabe & Rolls, 2007; O'Doherty, Rolls, Francis, Bowtell, & McGlone, 2001; Rolls & Baylis, 1994). It is generally assumed that qualitative and quantitative aspects of taste are processed in the operculum and insula, which represent the primary cortical taste zone, (Dalenberg, Hoogeveen, Renken, Langers, & ter Horst, 2015; Iannilli, Noennig, Hummel, & Schoenfeld, 2014; Mascioli et al., 2015) while the reward value and subjective well-being of food are processed in the orbitofrontal cortex (OFC) as secondary cortical taste zone (Kringelbach, O'Doherty, Rolls, & Andrews, 2003; Rolls, 2015; Small et al., 2007; Small, 2012). Minematsu, Ueji, and Yamamoto (2018) showed that activity changes within different areas of the prefrontal cortex (PFC) can be an effective method to objectively evaluate the pleasantness of food and drinks in addition to subjective evaluation with sensory tests. The authors reported tendencies that pleasant tastes decrease oxygenated hemoglobin (oxyHb) in the PFC, while unpleasant tastes might increase them (Minematsu et al., 2018). Moreover, the lateral prefrontal cortex (lPFC) seems to be a critical area for cognitive processing of taste and other food-related behaviors (Kringelbach et al., 2003). The dorsolateral prefrontal cortex (dlPFC) is involved in memory formation associated with taste and the ventrolateral prefrontal cortex (vlPFC) is activated by the perception of taste (Bembich et al., 2010; Okamoto et al., 2006; Okamoto, Dan, Clowney, Yamaguchi, & Dan, 2009; Rudenga & Small, 2013).

In this study, a new imaging processing technology called functional near-infrared spectroscopy (fNIRS) was used, which overcomes several of the restrictions of the neuroscientific methodologies used so far and can be combined with a sensory measurement. fNIRS is a noninvasive spectrographically technique to monitor changes in the blood oxygenation and blood volume. This imaging method uses near-infrared light to make changes in oxygen-level visible. Light is transmitted through the intact scalp, skull and subarachnoid space to the upper layers of the cerebral cortex. Because of the comparatively low absorption of water and hemoglobin in this spectral region, tissue penetration of up to 8 cm is possible (Jackson & Kennedy, 2013). fNIRS is comparably tolerant of body movements and less restrictive, allowing neuronal activations in taste experiments to be studied under more natural conditions (Krampe, Strelow, Haas, & Kenning, 2018). This is advantageous since difficulties in tasting due to restricted or unnatural body positions can cause an additional cognitive load for the test persons (Minematsu et al., 2018).

As a product-case, the sensory perception of plant-based milk alternatives was investigated, because understanding the perceptions and acceptability of plant-based milk alternatives is critical when (1) evaluating the taste process overall and (2) when discussing the reduction of animal products to ensure a sustainable food system. In view of the growing world population, the worldwide consumption of animal-based food needs to be drastically reduced to ensure a sustainable food system (Willett et al., 2019). Many consumers are interested in reducing the proportion of animal-based products in their diet (McClements et al., 2019). The study aimed to determine whether and how different taste nuances of two plant-based milk alternatives (a more bitter and a sweeter milk alternative) are reflected in the neuronal data of the subjects and how they are perceived. Sweetness is often considered as a pleasant sensation, while bitterness is often classified as an aversive taste. Since the sense of taste perceives both harmful and beneficial things, all basic tastes are classified as either aversive or appetitive depending on their effect on the body. Thus, salty, sweet, and umami are often associated with an intake of essential nutrients, while bitter and sour indicate potentially harmful substances (Hu, Kato, & Luo, 2014). Thus, the emotions evoked by taste are related to food regulation, dietary balance, and harm avoidance. As the PFC plays an important role in higher cognitive functions (Kringelbach, Araujo, & Rolls, 2004), it is assumed that processing pleasant and unpleasant taste lead to activation of parts of the PFC.

The focus of this study was not yet on evaluating and validating a differentiated hedonic scale in the brain, but on determining if fNIRS can be used for consumer sensory research in combination with hedonic measurements under realistic conditions (real-laboratory), which is why the hedonic scale was used to link the taste evaluations to the fNIRS data. Therefore, following hypotheses were under investigation:

> H1: Different taste nuances of plant-based milk alternatives lead to distinct neural activation patterns in the PFC.
>
> H2: The taste of water differs in the neural data compared to the plant-based milk alternatives.

Methods

Subjects

A total of 104 German students were recruited at a German university to take part in the study, which was conducted between August 6 and August 18, 2020. All participants gave their written consent to take part in this study and received monetary compensation at the end as a remuneration for time allowance (€10). Before the start of the experiment, the subjects were informed about the test procedure, the safety of the experiment, the security of their data, and that they could withdraw from the study at any time without consequences. The study was conducted in accordance with the Declaration of Helsinki and with the principles of the ICC/ESOMAR Code. The procedure and the use of fNIRS were approved by the Ethical Committee of the University. Thirteen participants had to be excluded due to poor data quality (seven participants), errors during data recording (two participants), or screen-outs from the questionnaire (four participants), leaving a total of $N = 91$ for analysis (62 females and 29 males; median age: 30; mean BMI: 22.2).

Stimuli

The tasting was carried out blind, i.e., the test persons knew that they would taste different types of plant-based milk alternatives, but not the type, brand, sequence, and quantity of substitutes. In each run, subjects either had to drink 2 centiliter (cl) of a plant-based milk sample or an equivalent amount of water. The plant-based milk alternatives samples used in this study were almond milk (almond drink: water, almonds (from organic farming) 7%, sea salt) and oat milk (oat drink: water, oats 10%, rapeseed oil, calcium carbonate, calcium phosphates, salt, vitamins (D2, riboflavin, B12), potassium iodide). These two products were chosen because the descriptive testing of a trained panel, which was part of a previously conducted unpublished research project of another working group (research project “NES” (Sustainable diets)), of the university of Goettingen with different plant-based milk alternatives described the taste profiles as rather contrasting (palatable vs. non-palatable). The taste of the selected almond milk was rated by the trained panel as rather nutty, bitter, and slightly sour. The taste of the oat milk, on the other hand, was rated as more cereal-like and sweeter. The water sample was used as a control condition to measure cognitive differences between the milk samples.

Procedure

To assure the same circumstances for every participant, the experiment was conducted in a small, windowless room without furniture or wall decoration. It was ensured that the light did not fall directly on the fNIRS setup or on the screen to avoid influencing the subjects’ view and to ensure constant lightening-conditions. During the procedure, the subjects were informed about the study procedure and that they had the opportunity to ask questions and withdraw at any given time. They were asked to sit on a chair two meters in front of a wall screen, which displayed the instructions of the experiment. Then they were fitted with the fNIRS headband and asked to remain as calm as possible during the whole experiment and to avoid strong head movements. The fNIRS experiment was combined with a hedonic sensory approach (description explicitly underneath). After completing the fNIRS part of the experiment, the participants’ headband was removed again. The subjects then had to fill in a questionnaire, which was completed in an adjacent room so that the fNIRS experiment room could be disinfected, aired out, and prepared for the next participant.

Experimental Design

The design consisted of three experimental conditions (“taste” condition for two plant-based milk alternatives samples and a water sample as a reference value) and one control condition (neutral, shown as "X") (see Figure 1). The experimental design was pre-randomized to simplify the preparation of the taste samples and to exclude repetition effects. Each subject was randomly assigned to one of the experimental design versions. The subjects' task was to rest for 20 s, take and leave the sample into their mouth for 25 s, swallow it for 3 s, and taste it for another 25 s (see Figure 1). Then consumers rated the overall liking of the samples on a hedonic scale from one to nine points (1 = dislike extremely; 5 = neither like or dislike; 9 = like extremely). Afterwards, the subjects neutralized their taste buds with water and cucumber slices for 25 s. This was followed by a 30-s break, in which the participants could relax while the next sample was handed by the experimental personnel. In total, each of the three samples was tasted three times. The stimuli repetition frequency was kept low compared to other fNIRS or fMRI studies to keep the study as consumer-friendly as possible and to make a compromise between classical sensory research, where stimuli are even partially tasted only once, and fNIRS research. The drinking repetition frequency can also be found in other fNIRS drinking studies (Minematsu et al., 2018; Van Rijn, de Graaf, & Smeets, 2018; Imoto et al., 2018). The average time of the fNIRS experiment was 20.1 min representation.

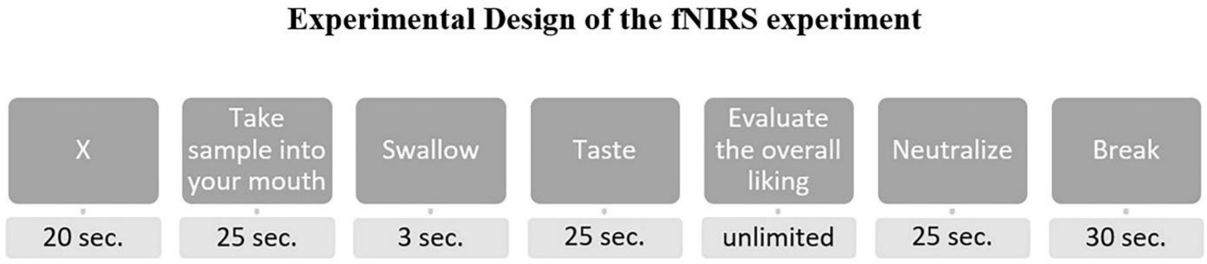

Figure 1: Schematic of the experimental design.

The questionnaire following the experiment was used to derive the consumption motives of the participants. In addition to socio-demographic information, the previous consumption frequency of plant-based drinks and preferred varieties were queried. In addition, subjects were asked about their perceptions of the samples and the procedure in general.

fNIRS Measurement

FNIRS allows a continuous determination of time-dependent concentration changes of the two hemoglobin forms in the permeable tissue by continuous individual measurements during the measurement period. Changes in the concentration of oxygenated (oxyHb) and deoxygenated hemoglobin (deoxyHb) represent the basic physiological parameters of fNIRS in analogy to fMRI, which gather the blood-oxygen-level-dependent (BOLD) signals from the paramagnetic properties of hemoglobin (Moro, Cutini, Ursini, Ferrari, & Quaresima, 2013). The principle of neurovascular coupling allows the comparison of the fNIRS signals with the fMRI signals (Girouard & Iadecola, 2006; Plassmann et al., 2015).

In this study, the optical signals were recorded using a mobile two-wavelength continuous imaging NIRSport system (NIRx Medical Technologies, Berlin, Germany) that simultaneously collected data at a sampling rate of 7.91 Hz and with wavelengths of 760–850 nm. The neoprene headband consisted of eight near-infrared light sources (diodes) and seven detectors (optodes), which resulted in 22 measurement channels (see Figure 2). Optodes and diodes were separated from each other by 3 cm to enable an optimal scattering of light (Jackson & Kennedy, 2013). To guarantee the correct fit according to the anatomical brain structures of the subjects we used the craniometric points of the head (the nasion was used as a measurement point to place source number 7) to position the headband directly on the participants' forehead.

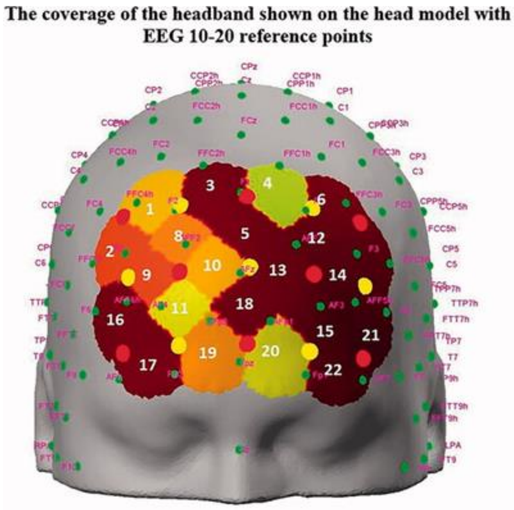

Figure 2: The coverage of the headband shown on the head model with EEG 10-20 reference points and detectors (yellow) and sources (red) placement. Adjacent sources and detectors result in one measurement channel (channels 1–22).

Note: Here, the coloring has no meaning. Mapping out of nirsLAB.

For fNIRS measurements of the brain regions of interests, the specific probe placements need to be relayed to corresponding brain areas. Here, an approach that automatically translates the probe positions based on the 10–10 EEG-system (Jurcak, Tsuzuki, & Dan, 2007) into the Brodmann parcellation atlas, was applied. In it, the cerebral cortex is divided into fields that differ in the structure and cytoarchitecture of their layers due to their different functions, so-called Brodmann areas. The mapping of the activated brain areas resulting from the experimental stimuli was done with the fOLD toolbox (v2.2) which uses also the Brodmann atlas. In our experiment parts of Brodmann areas 9, 10, 11, and 46 were covered. Channels 1, 3, 4, 5, 6, 8, 9, 12, 14 and 16 can be assigned to Brodmann area 46 and area 9, which represents parts of the dlPFC. Channels 10, 11, 13, 15, 17, 18, 19, and 20 were assigned to Brodmann area 10, which maps parts of the frontopolar area of the PFC, the anterior PFC (aPFC), and channels 17, 19, 20 and 22 were assigned to Brodmann area 11, mapping parts of the orbitofrontal cortex (OFC). A schematic representation of the coverage on a brain map is shown in Figure 2.

Data Analysis

Before analyzing the data, data quality was verified by comparing the signal-to-noise ratio of each channel with the coefficient of variation (CV). Channels with a value above the threshold of 9.0 (default value) were marked as inadequate and excluded from the following analysis. Participants with half or more inadequate channels were excluded from further analysis. To smooth the raw data, a band-pass filter (high/low frequency filter of 0.01–0.2 Hz) was applied to control for possible artifacts (e.g., movement, heartbeat, etc.) that might interfere with the measurement of the intended effects. Strong motion artifacts and discontinuities were removed manually as well. Then, concentrations of oxyHb and deoxyHb were detected by applying a modification of the Beer-Lambert law to the raw data of the 22 channels. For further analysis, we concentrated on the oxyHb values because they seem to correlate more strongly with the cerebral blood flow (Hoshi, 2007).

The fNIRS data analysis consisted of the statistical parametric mapping (SPM) Level 1 and SPM Level 2. First, data were analyzed for each subject individually, while in the second part, the results were analyzed for all subjects within the group. We focused on differences in neuronal activity when tasting the different plant-based milk alternatives. To model neural activity during the experimental conditions, a General Linear Model (GLM) was estimated for every participant. We group-modelled the parameters of the individual experimental trials, leading to four event-related regressors and the constant error term ($Yj = xj1\beta1 + xj2\beta2 + xj3\beta3 + xj4\beta4 + \varepsilon j$). A one-sided t-test was used to measure the differences; the significance level was set to 1%. In a first step (I), the main effect of the experimental conditions (the taste phase) was compared with the baseline. Then, t-contrasts were calculated for the whole group (II) to compare the experimental conditions with the control condition ("oat/almond milk/water taste" vs. "break") and (III) to compare the experimental conditions among each other ("oat milk taste" vs "almond milk taste" vs "water taste"). In a fourth step (IV), a group was formed and analyzed based on the evaluations of the overall liking. The threshold brain activation maps were then plotted on the standardized head model (ICBM-152) which is included in the nirsLAB software. The different activity levels which are expressed in t-values, were displayed in red or blue shades, where red represents a high t-value and correspondingly a high neuronal activity. Multiple comparison corrections were performed using Bonferroni correction, where the statistical significance level (α) is divided by the number of channels (M) ($\alpha Bonf = \alpha/M$).

The experimental design was created using the stimulus delivery program Presentation from Neurobehavioral Systems (version 20.03). The NIRStar software package (version 15.2) was used to check for signal quality and to collect data. The Lab Streaming Layer (LSL) allowed us to synchronize the recorded data from NIRStar and Presentation. The data evaluation and statistical analyses were performed with the software nirsLAB (version 2019.04). The questionnaire was created with the online survey software Unipark from Questback. The evaluation of the sensory results and the survey were analyzed descriptively using SPSS (IBM, SPSS Statistics 26) and Microsoft Excel (Professional Plus 2019). A single factor analysis of variance (ANOVA) was used to calculate differences between the mean values of the evaluation of overall liking.

Results

Subjective Ratings and Consumption Behavior

The participants evaluated the overall taste of the two plant-based milk alternatives and of the water sample. The oat milk had the best overall rating (mean: 7.0 points, SD: 1.5) the almond milk the worst (mean: 3.9 points, SD: 1.7) (see Figure 3). The water was characterized by a neutral taste and was rated on average with five scale points, which confirms the neutral taste (mean: 5.4 points, SD: 1.6). The ratings of the three samples differed significantly from each other ($p < 0.001$).

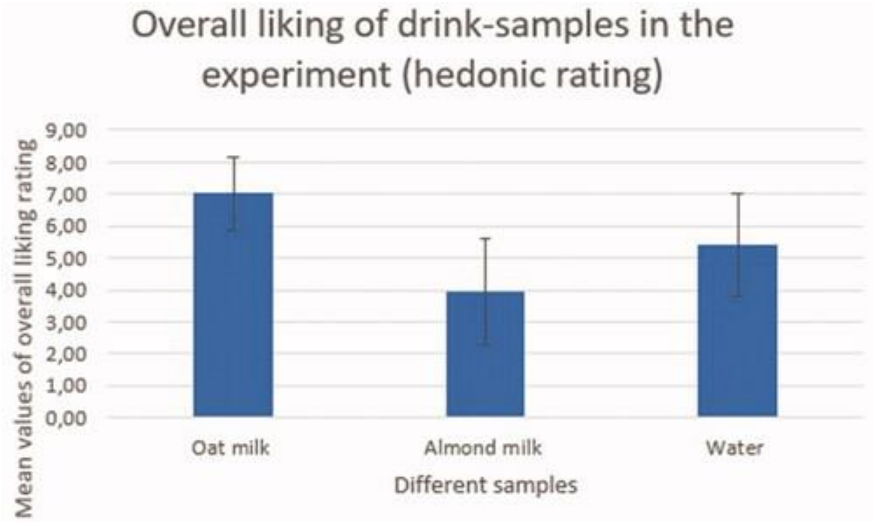

Figure 3: Evaluation of overall liking of plant-based milk and water samples.

Note: Relative distribution frequencies are displayed. Subjects evaluated each sample three times on a scale from 1 (does not taste good at all) to 9 (tastes very good), N = 91

When it comes to the distribution of the overall liking, the oat milk was given a rating higher than 6 points (6–9 points) by 84 subjects (92%) (see Table 1). Only 2% of the subjects rated the overall liking between 1–4 points and five subjects with 5 points (= "tastes neither good nor bad"). The overall liking of the almond milk, on the other hand, was rated between 1 and 4 points by 63% of the subjects and between 6 and 9 points by 21% of the subjects. Another 16% gave this plant-based milk 5 points (= "tastes neither good nor bad"). The water sample was mainly rated with 5 points by 62% (56 subjects). Another 24% of the subjects evaluated the overall liking between 6 and 9 points and 14% between 1 and 4 points.

Table 1: Evaluation overall liking according to evaluation sections, N = 91.

	Oat milk	**Almond milk**	**Water**
1 to 4 points	2%	63%	14%
5 points	5%	16%	62%
6 to 9 points	92%	21%	24%

The time until a rating was given decreased over time. Subjects took an average of 7.91 seconds (SD = 3.19) to evaluate the overall liking of the first sample and an average of 5.12 seconds (SD = 1.68) for the last sample. However, no correlation could be detected between the evaluation time and the rating of the taste samples. In a free text field of the questionnaire, subjects were asked to indicate how many varieties they had tasted. As it was a free text task, the answers overlapped slightly. Around 58% of respondents said they had tasted between two and three different samples. Another 33% said they had tested between four and five samples, and nearly 9% said they had drunk between three and four different samples.

Further, subjects were asked if they had already consumed plant-based milk alternatives products previously. A total of 44% of the subjects stated that they consumed plant-based milk alternatives several times a day or daily. Another 22% claimed to consume plant-based milk alternatives several times a week or once a week, 7% of the subjects consumed plant-based milk only once a month, and 19% consumed it once a month or less frequently. The most popular types were oat milk (58%), almond milk (16%), and soy milk (10%).

fNIRS data

In addition to the results listed below, threshold t-tests were also performed to compare the experimental conditions with each other. At first the main effects will be described, so the results of the experimental conditions during the tasting phase will be compared with the results from the baseline measurements. Then results of the within-contrasts of the experimental conditions (“oat/almond milk/water taste” and the control condition (“break”) as well as the experimental conditions among each other will be presented. Finally, hedonic overall-liking (using end-points) will be used to confront hedonic scales with the fNIRS-measurement.

Main effects of the experimental conditions

The main effects of the experimental conditions in comparison to the baseline can be associated with a neural activity in parts of the dlPFC (see Table 2). In specific: The “oat milk taste” condition significantly increased neural activity ($p < 0.01$) in parts of the dlPFC (channel 1: $t(91) = 5.04$, $d = 1.05$, $p = 0.000$; channel 5: $t(91) = 7.18$, $d = 1.47$, $p = 0.000$; channel 6: $t(91) = 5.00$, $d = 1.05$, $p = 0.000$; channel 8: $t(91) = 5.66$, $d = 1.05$, $p = 0.000$; channel 9: $t(91) = 7.53$, $d = 1.47$, $p = 0.000$; channel 12: $t(91) = 6.71$, $d = 1.26$, $p = 0.000$; channel 14: $t(91) = 6.17$, $d = 1.26$, $p = 0.000$), parts of the aPFC and the OFC (channel 10: $t(91) = 8.48$, $d = 1.68$, $p = 0.000$; channel 11: $t(91) = 6.17$, $d = 1.26$, $p = 0.000$; channel 17: $t(91) = 6.96$, $d = 1.28$, $p = 0.000$; channel 18: $t(91) = 8.25$, $d = 1.68$, $p = 0.000$; channel 19: $t(91) = 6.39$, $d = 1.26$, $p = 0.000$; channel 20: $t(91) = 6.30$, $d = 1.26$, $p = 0.000$; channel 22: $t(91) = 5.72$, $d = 1.05$, $p = 0.000$) (see Figure 4 (A)).

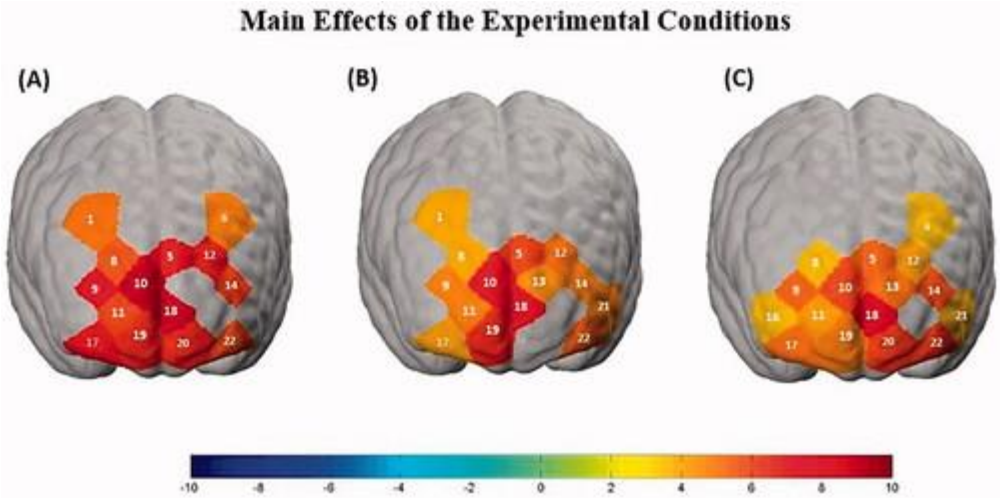

Figure 4: Significantly increased neural prefrontal cortex activity for the main effects of the “oat milk taste” (left brain), “almond milk taste” (middle brain), “water taste” (right brain). The activation threshold was set to $p < 0.01$.

Table 2: *p* and *t*-values of the single fNIRS channels of the main effect of oat milk taste, almond milk taste and water taste in association with the Brodmann areas (BA).

Channel		Brodmann Area	p-value	t-value	d
1		**BA 46 & BA 9**			
	Main effect oat milk taste		0,000	5,04	1,05
	Main effect almond milk taste		0,000	3,81	0,63
5		**BA 46 & BA 9**			
	Main effect oat milk taste		0,000	7,18	1,47
	Main effect almond milk taste		0,000	6,14	1,26
	Main effect water taste		0,000	5,47	1,05
6		**BA 46 & BA 9**			
	Main effect oat milk taste		0,000	5	1,05
8		**BA 46 & BA 9**			
	Main effect oat milk taste		0,000	5,66	1,05
	Main effect almond milk taste		0,000	3,85	0,63
9		**BA 46 & BA 9**			
	Main effect oat milk taste		0,000	7,53	1,47
	Main effect almond milk taste		0,000	4,78	0,84
	Main effect water taste		0,000	5,50	1,05
10		**BA 10**			
	Main effect oat milk taste		0,000	8,48	1,68
	Main effect almond milk taste		0,000	7,22	1,47
	Main effect water taste		0,000	6,09	1,26
11		**BA 10**			
	Main effect oat milk taste		0,000	6,17	1,26
	Main effect almond milk taste		0,000	4,87	0,84
	Main effect water taste		0,000	4,27	0,84
12		**BA 46 & BA 9**			
	Main effect oat milk taste		0,000	6,71	1,26
	Main effect almond milk taste		0,000	5,17	1,05
	Main effect water taste		0,000	4,31	0,84
13		**BA 10**			

Channel		Brodmann Area	p-value	t-value	d
	Main effect almond milk taste		0,000	4,39	0,84
	Main effect water taste		0,000	5,15	1,05
14		**BA 46 & BA 9**			
	Main effect oat milk taste		0,000	6,17	1,26
	Main effect almond milk taste		0,000	4,96	0,84
	Main effect water taste		0,000	5,70	1,05
17		**BA 10 & BA 11**			
	Main effect oat milk taste		0,000	6,96	1,28
	Main effect almond milk taste		0,000	4,35	0,84
	Main effect water taste		0,000	5,14	1,05
18		**BA 10**			
	Main effect oat milk taste		0,000	8,25	1,68
	Main effect almond milk taste		0,000	7,60	1,47
	Main effect water taste		0,000	7,83	1,45
19		**BA 10 & BA 11**			
	Main effect oat milk taste		0,000	6,39	1,26
	Main effect almond milk taste		0,000	6,39	1,26
	Main effect water taste		0,000	4,86	0,84
20		**BA 10 & BA 11**			
	Main effect oat milk taste		0,000	6,30	1,26
	Main effect water taste		0,000	5,97	1,05
21		**BA 46 & BA 9**			
	Main effect almond milk taste		0,000	4,69	0,84
	Main effect water taste		0,000	3,84	0,63
22		**BA 11**			
	Main effect oat milk taste		0,000	5,72	1,05
	Main effect almond milk taste		0,000	5,55	1,05
	Main effect water taste		0,000	6,09	1,26

The “almond milk taste” condition significantly increased neural activity ($p < 0.01$) in parts of the dlPFC (channel 1: $t(91) = 3.81$, $d = 0.63$, $p = 0.000$; channel 5: $t(91) = 6.14$, $d = 1.26$, $p = 0.000$; channel 8: $t(91) = 3.85$, $d = 0.63$, $p = 0.000$; channel 9: $t(91) = 4.78$, $d = 0.84$,

$p = 0.000$; channel 12: $t(91) = 5.17$, $d = 1.05$, $p = 0.000$; channel 14: $t(91) = 4.96$, $d = 0.84$, $p = 0.000$; channel 21: $t(91) = 4.69$, $d = 0.84$, $p = 0.000$), parts of the aPFC, and the OFC (channel 10: $t(91) = 7.22$, $d = 1.47$, $p = 0.000$; channel 11: $t(91) = 4.87$, $d = 0.84$, $p = 0.000$; channel 13: $t(91) = 4.39$, $d = 0.84$, $p = 0.000$; channel 17: $t(91) = 4.35$, $d = 0.84$, $p = 0.000$; channel 18: $t(91) = 7.60$, $d = 1.47$, $p = 0.000$; channel 19: $t(91) = 6.39$, $d = 1.26$, $p = 0.000$; channel 22: $t(91) = 5.55$, $d = 1.05$, $p = 0.000$) (see Figure 4 (B)).

The "water taste" condition significantly increased neural activity ($p < 0.01$) in parts of the dlPFC (channel 5: $t(91) = 5.47$, $d = 1.05$, $p = 0.000$; channel 9: $t(91) = 5.50$, $d = 1.05$, $p = 0.000$; channel 12: $t(91) = 4.31$, $d = 0.84$, $p = 0.000$; channel 14: $t(91) = 5.70$, $d = 1.05$, $p = 0.000$; channel 22: $t(91) = 6.09$, $d = 1.26$, $p = 0.000$), parts of the aPFC, and the OFC (channel 10: $t(91) = 6.09$, $d = 1.26$, $p = 0.000$; channel 11: $t(91) = 4.27$, $d = 0.84$, $p = 0.000$; channel 13: $t(91) = 5.15$, $d = 1.05$, $p = 0.000$; channel 17: $t(91) = 5.14$, $d = 1.05$, $p = 0.000$; channel 18: $t(91) = 7.83$, $d = 1.45$, $p = 0.000$; channel 19: $t(91) = 4.86$, $d = 0.84$, $p = 0.000$; channel 20: $t(91) = 5.97$, $d = 1.05$, $p = 0.000$; channel 21: $t(91) = 3.83$, $d = 0.63$, $p = 0.000$) (see Figure 4 (C)).

Experimental conditions compared to control condition

The experimental conditions ("oat milk taste," "almond milk taste," and "water taste") compared to the control condition ("neutral," shown as X) can be associated with the following results (see Table 3): For all groups, at a significance level of $p < 0.01$, decreased neuronal activity could be measured in one channel (channel 5 oat milk taste: $t(91) = -3.62$, $d = -0.63$, $p = 0.000$ (see Figure 5 (A)); channel 5 almond milk taste: $t(91) = -3.69$, $d = -0.63$, $p = 0.000$ (see Figure 5 (B)); channel 5 water taste: $t(91) = -3.93$, $d = -0.63$, $p = 0.000$) (see Figure 5 (C)). All three conditions showed decreased neural activations in the dlPFC.

In regard to the comparison of the experimental conditions among each other ("oat milk" vs "almond milk" vs "water"), no significant differences were detected. Hence, neither taste-condition was generating a response measurable with the applied setup.

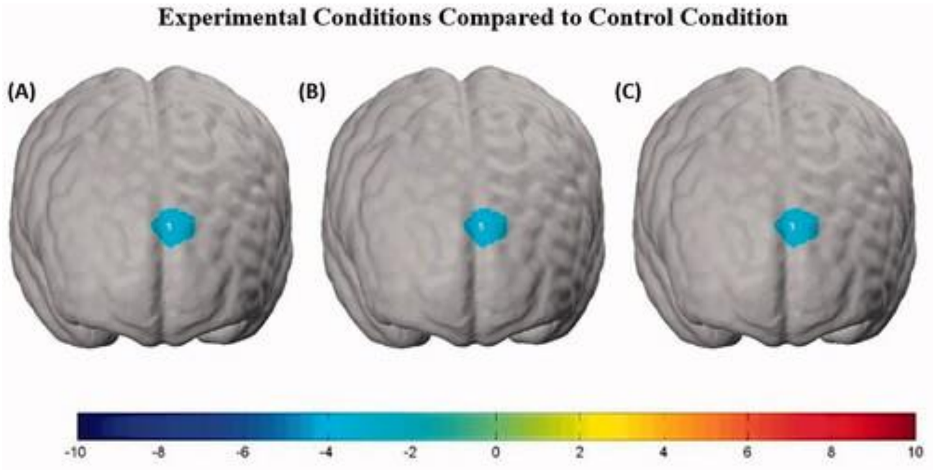

Figure 5: Significantly decreased neural prefrontal cortex activity for the contrast between the "oat milk taste," "almond milk taste," and "water taste" compared to the "neutral taste," shown as X. The activation threshold was set to $p < 0.01$.

Table 3: *p* and *t*-values of the single fNIRS channels for the effect of oat milk taste vs. neutral, almond milk taste vs. neutral and water taste vs. neural in association with the Brodmann areas.

Channel		Brodmann Area	p-value	t-value	d
5		**BA 46 & BA 9**			
	Oat milk taste vs. neutral		0,000	-3,62	-0,63
	Almond milk taste vs. neutral		0,000	-3,69	-0,63
	Water taste vs. neutral		0,000	-3,93	-0,63

Group taste discriminator: experimental conditions compared to control condition

In a next step, a group was formed with subjects who rated the oat milk as well-tasting (greater than scale point '5') and the almond milk bad-tasting (less or equal to scale point '4') in order to methodologically compare the hedonic scales with the fNIRS in regard to "end-point-comparisons" (see Table 4). Scale point '5' was deliberately not considered, as it represented a neutral taste. Accordingly, 53 out of 91 subjects were identified for this group.

The conditions of "oat milk taste" vs "neutral," shown as X, resulted in a response, detectable in the dlPFC, across all participants, with significantly decreased neural activity at a significance level of $p < 0.01$, in channel 5 ($t(53) = -3.37$, $d = -0.63$, $p = 0.001$) and channel 12 ($t(53) = -3.15$, $d = -0.63$, $p = 0.002$) (see Figure 6 (A)).

Table 4: *p* and *t*-values of the single fNIRS channels for the effect of the taste discriminator group: oat milk taste vs. neutral and almond milk taste vs. neutral in association with the Brodmann areas.

Channel		Brodmann Area	p-value	t-value	d
5		**BA 46 & BA 9**			
	Group taste discriminator: Oat milk taste vs. neutral		0,001	-3,37	-0,63
	Group taste discriminator: Almond milk taste vs. neutral		0,001	-3,29	-0,63
12		**BA 46 & BA 9**			
	Group taste discriminator: Oat milk taste vs. neutral		0,002	-3,15	-0,63

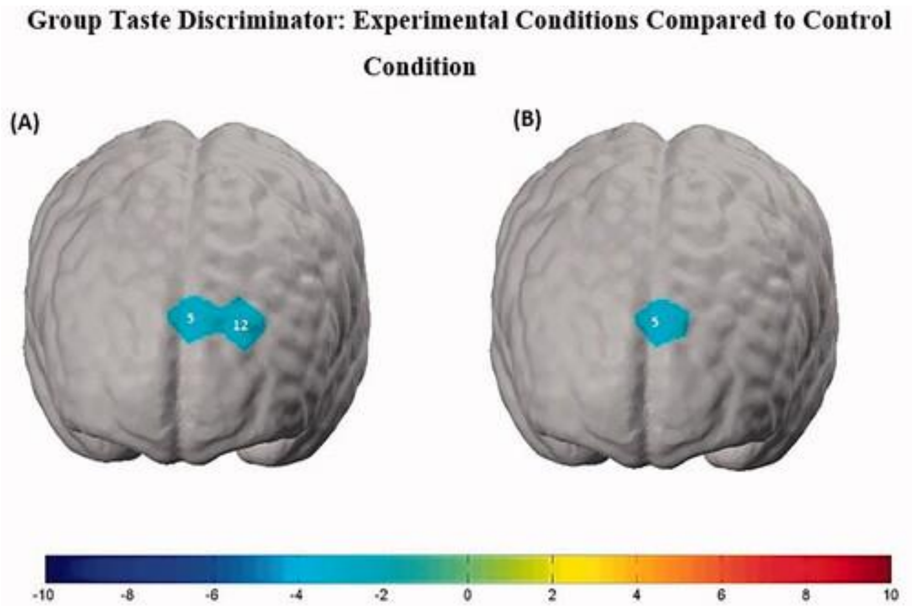

Figure 6: Significantly increased neural prefrontal cortex activity for the contrast between the "oat milk taste" (left brain) and "almond milk taste" (right brain) compared to the "neutral taste," shown as X. The activation threshold was set to $p < 0.01$.

The conditions of "almond milk taste" vs. "neutral," shown as X, also revealed significantly decreased neural activity at a significance level of $p < 0.01$ in channel 5 ($t(53) = -3{,}29$, $d = -0.63$, $p = 0.001$) (see Figure 6 (B)).

Hence, in addition to the above, no further details in regard to taste evaluation processing could be unveiled. However, the location for assessing the sensory properties of taste could be reaffirmed using classical hedonic scales, even in the end-points.

Discussion and Conclusion

This study aimed to explore whether fNIRS in combination with hedonic measurements under realistic conditions (real-laboratory) can be used for sensory consumer research. Moreover, it was aimed to combine three disciplines, consumer studies, sensory science and consumer neuroscience to gain a better understanding of consumer-decision-making in food choices. The results from the consumer and sensory studies showed that the subjects significantly preferred the taste of the oat milk over the taste of the almond milk. Water was characterized as neutral tasting. We expected these results, as the products were tested in advance by a panel and the oat milk was rated as more cereal-like and sweeter, while the almond milk was rated as rather nutty, bitter, and slightly sour. This is not unusual, as sweet tastes are often rated as more palatable and more pleasant, whereas bitter tends to be perceived as rather unpleasant. The consumer neuroscience results, which included the sensory tasting of all different plant-based milk alternatives and water, resulted in hemodynamic responses in different parts of the PFC.

Comparing the “oat/almond/water taste” condition with the neutral condition (shown as X), significant neuronal activity was measured in one channel of the dlPFC (channel 5) that is part of Brodmann areas 46 and 9. A deactivation in the dlPFC (channels 5 and 12 for oat milk and channel 5 for almond milk) was also measured in the group that rated the taste of the oat milk higher than the one of the almond milk. Thus, no distinctions could be detected between the whole group and the group with participants who clearly preferred oat milk over almond milk. In our study, we measured a relative decrease in oxyHb during taste processing located to one channel in the dlPFC. The representations of taste in the human brain have also shown that the dlPFC, which is part of the secondary cortical taste zone, revealed cognitive and emotional aspects of taste perception and the perceived pleasantness (Iannilli et al., 2014; Rolls, 2015; Small et al., 1999, 2007; Small, 2012). Moreover, the dlPFC is an area where the consequences of actions, such as delivery of a particular taste of flavor may affect cognition, given that the dlPFC is directly implicated in the preparation for and selection of responses (Kringelbach et al., 2004). In our case this implies that it may be possible to measure taste-related processes resulting from the different plant-based milk alternatives with fNIRS, although the measurement might have not been specific enough to detect differences between slightly varying flavor and aroma profiles. This would have to be considered, especially in light of the fact that neither of the two plant drink products (nor the water) was rated as having a strongly off-putting taste.

A study by Minematsu et al. (2018) showed tendencies that activity changes within the area of the aPFC can be used as an effective method for the objective evaluation of the pleasantness of food and drinks in addition to subjective evaluation with sensory tests. This was reflected in increased oxyHb levels for unpleasant and decreased oxyHb levels for pleasant edibles. These results were also found when viewing images. A study by Hoshi et al. (2011) suggests that the lateral part of the PFC is involved in emotions, as viewing unpleasant images was associated with an increase in oxyHb, while pleasant images were associated with a decrease in oxyHb (Hoshi et al., 2011). For us, this could possibly mean that also the neuronal data points into the direction that the plant-based milk alternatives were rated rather acceptable and not truly inedible (in the hedonic test they rated oat milk with a mean of 7.0 points and almond milk with a mean of 3.9 points). This would then suggest that at least the direction of taste (rather pleasant vs. rather unpleasant) could possibly be detected with the neuronal data. Hence, future studies may need a higher contrast regarding the palatability in order to increase the fNIRS response.

However, no neuronal difference in the specific taste evaluation of the two plant-based milk alternative samples was detected. Although they differed in taste, this could not be reflected in the neuronal data of the PFC. fMRI studies have shown that when processing sweet or bitter taste, other areas of the human brain are involved, such as the primary taste areas of the mid-insula, anterior insula, frontal operculum, central operculum, precentral gyri, and thalamus (Roberts et al., 2020). This again indicates that the fNIRS assessment may be able to visualize the taste process activation, but cannot assign a differentiated hedonic preference evaluation, because the qualitative evaluation of taste differences may be processed in deeper or more complex regions of the brain (Avery et al., 2020).

However, it should also be considered that frequent repetition of drinking can lead to taste overlaps. Therefore neutralization after each sample is important. In some cases, the subjects had difficulty estimating the number of samples they drunk. Hence, it may be possible that the response is detectable using fNIRS, but it may be that the qualitative evaluation of taste differences may be processed in deeper or more complex regions of the brain (Avery et al., 2020).

Merits and limitations

This study is one of the first to tackle the process of sensory evaluation combining hedonic scales with fNIRS measurements. A key limitation of fNIRS compared to fMRI is poorer spatial resolution. With fNIRS, only the superficial areas of the brain can be measured, such as the prefrontal cortex. Deep brain structures, such as the frontal/parietal operculum or the insula, where taste-related areas are also located, cannot be measured with fNIRS. Additionally, this makes it more difficult to accurately localize the activated areas, as they are difficult to distinguish from each other.

Moreover, the sample was rather homogeneous in terms of age and educational background, and we had an above-average number of women as well as participants who already consume plant-based milk alternatives products on a regular basis. Therefore, the subjects were probably already accustomed to the taste of the two plant-based milk alternatives. Future studies should build on the given findings, recruiting more heterogenous participants as well as using higher contrasts regarding taste evaluation in order to reflect back habituality as well as process-evaluation schemes to be detectable with fNIRS.

To conclude, overall a (stable) decrease of activity in the dlPFC was measured while tasting, but no significant differences between the two taste samples and the water sample could be measured using fNIRS in this sensory experiment. This may be because the taste differences were not strong enough, in terms of their contrast, to be measured with fNIRS. However, it seems that at least the direction of taste (rather pleasant vs. rather unpleasant) could possibly be made visible with the neuronal data. Generally in sensory research, the mental processes and underlying brain functions of taste evaluations in their nuances are much less understood, especially in the PFC. Nonetheless, as it was the study’s purpose to a find a better, but yet accessible way to assess consumer behavior, the measurement was combined with classical tests of hedonic rating to confront and attach to the status-quo of the scientific communities and discuss the findings against the established procedures and further developments. Our results provide first insights into understanding consumer preference evaluation and processing. This exploratory finding may suit to equip the scientific communities with the usage of fNIRS in the context of sensory research and can be used by future studies as a foundation for assessing consumers’ sensory and neuronal perceptions.

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Article 5:

PACE Labels in Healthy and Unhealthy Snack Products in a Laboratory Shopping Setting: Perception, Visual Attention, and Product Choice

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4.5 PACE Labels in Healthy and Unhealthy Snack Products in a Laboratory Shopping Setting: Perception, Visual Attention, and Product Choice

Abstract

Informative food labels are one way to increase nutritional awareness in society and can essentially help individuals maintain balanced dietary practices. Nonetheless, making food labels 'informative', in the sense of applicability, is not always easy. Physical activity calorie equivalent (PACE) food labeling is one approach to achieve this goal. Yet, it is neither understood how consumers perceive PACE labels, nor how effective they are in regards to healthy food choices. Moreover, it is of interest to assess the perception of real products in close-to-realistic environments. Therefore, this study examined a simulated purchase situation and consumers' visual attention on PACE labels—on 20 different real snack products with varying health values. In a laboratory-shopping environment, the gaze behaviors of 91 consumers were examined with head-mounted eye-trackers. In regards to perception, it was elucidated that every participant noticed at least one PACE label. On average 1.39 PACE label fixations on different products were counted with a mean fixation duration of 0.55 s and a mean time to first fixation of 22.46 s. On average, 22.9% of the participants viewed the PACE labels at least once, but the intensity and duration varied greatly between the different products; 'healthier products' attracted more visual attention than 'unhealthier products'. In regards to health choice, it became obvious that the choices observed were rather healthy and PACE labels attracted attention. This may have been especially true for participants with little involvement in physical activity and health behavior, which may have been the main target group. Hence, catchy, communicable PACE labels, as well as balanced product offerings may facilitate more healthy food choices. The real-world laboratory setting offered valuable insights, which should be followed-up on.

Keywords: eye-tracking; consumer behavior; calorie information; nutritional labeling; food-choice

Introduction

The global rising obesity rate (of almost 40%) will seriously burden national health systems (WHO, 2020; Yates et al., 2017). To face obesity and its associated secondary diseases, keeping a low-energy, micronutrient-rich diet, combined with sufficient physical exercise is one of the most important aims, especially in industrialized countries (Swinburn, Caterson, Seidell, & James, 2004). Due to changes in living and working conditions, individual habits, low levels of nutritional knowledge, and the constant availability of food and food cues in our society, maintaining this balanced diet currently poses as a challenge for many people (Swinburn, Egger, & Raza, 1999; Swinburn et al., 2011). One way to increase nutritional awareness and encourage healthier eating decisions is nutritional labeling, which is mandatory in many countries; for example, in European countries, the majority of pre-packed foods must have a nutrition declaration. However, it is known that the current front of pack (FoP) nutrition information on foods and beverages is limited in its effectiveness, because many consumers have difficulty processing the provided information (Cowburn & Stockley, 2005; Vanderlee, Goodman, Yang, & Hammond, 2012). This highlights the need for more easily understandable caloric information, provided in a more intuitive, yet action-oriented way, e.g., in the form of physical activity calorie equivalent (PACE) food labeling.

The idea of PACE labeling is to provide a translation to abstract to interpret product information, such as the calorie content information, into intuitive units. It interprets them as an equivalent to the number of calories contained in the specific product, e.g., as in this case in minutes to walk or to run. This is expected to simplify the processing of label information, as well as orienting it into an action-based result, because lower levels of nutritional and numerical competence are required (Blumenthal & Volpp, 2010; Masic, Christiansen, & Boyland, 2017).

Labeling intervention strategies aim to disrupt habitual food decision situations at the point of purchase and, therefore, focus on quickly catching consumers' attention by providing information that does not require deep cognitive processing (Machín et al., 2020). In this context, PACE labeling schemes seem particularly promising, because a combination of a colorful graphic with information about the content enables easy understanding, which is expected to shorten the processing time of the provided information (Bialkova et al., 2014; Siegrist, Leins-Hess, & Keller, 2015). This, again, may result in a greater influence of point-of-purchase labeling on consumer behavior towards healthier eating choices (Bleich, Barry, Gary-Webb, & Herring, 2014; Bleich, Herring, Flagg, & Gary-Webb, 2012; Daley, McGee, Bayliss, Coombe, & Parretti, 2020; Grunert & Wills, 2007; Masic et al., 2017; Vanderlee et al., 2012). Further, this approach might promote physical activity (Deery et al., 2019).

To the best of our knowledge, PACE labels are not yet in use, but the Royal Society for Public Health in the UK called for an introduction of PACE labeling in 2016 (RSPH, 2016). Until now, several studies and meta-analyses have shown effects of PACE labels in reducing calorie consumption and improving food choices. This especially describes the effects of the labels in comparison to the absence of food labels. Overall, PACE labels may have been effective at reducing the number of kilocalories of food consumed, but compared to calorie-only labeling, they did not reduce calorie consumption (Daley et al., 2020; Hartley, Keast, & Liem, 2018; Masic et al., 2017; Seyedhamzeh, Bagheri, Keshtkar, Qorbani, & Viera, 2018; Wolfson, Graham, & Bleich, 2017).

From a consumer point of view, the perception of PACE labels has not been sufficiently investigated. It is very likely that consumer perceptions of PACE labels are very different depending on the presentation of the experimental stimuli (product pictures vs. real products and single product vs. product category) (Daley et al., 2020). Most evidence from previous studies were from laboratory settings or hypothetical meal selection scenarios, and there has been a lack of studies that applied PACE labels in real-world settings or used real products to examine the perception of labels. This seems particularly critical against the background that PACE labels are discussed worldwide as an alternative labeling approach (Cramer, 2016). Therefore, in this study, we examined PACE labels that were realistically attached to various real snack products with differing health values, and presented in a laboratory-shopping shelf. The purpose was to obtain a better understanding of consumer perceptions of PACE labels, on real products, and the attention they gained in a simulated purchase situation. As traditional consumer research techniques allow only the measurement of conscious reactions to stimuli, we applied, in addition to a survey, a more indirect consumer neuroscience approach—eye-tracking technology. This enabled us to measure immediate, more unconsciously aroused physiological reactions to the PACE label stimuli. Hence, the overall hypothesis is that PACE labels need visual framing in order to be effective in calorie reductions. In order to come closer to test this, we designed the study to, at first, test the effectiveness of the visual stimuli.

In this paper, we investigated the visual attention of PACE labels, and whether they were fixated more intensely (in the sense of longer, faster, and more often) compared to other product information using eye-tracking technology (ET). Other product information, in our case, included the price of the product and the product as a whole. Further, we investigated if PACE labeling was effective in regards to product choices with different health values. Moreover, we investigated whether (and how) the participants perceived and remembered the PACE labels during purchasing. For this, we used a questionnaire and contrasted the results with the ET measurements.

Materials and Methods

Eye-Tracking Methodology

There is a need to measure the effects of nutritional labeling, not only with stated preferences or other retrospective methods, which are limited (i.e., in regards to the relevance and external validity of their findings), but also with actual behavioral measurements (Ares et al., 2013). To examine the basis of consumer behavioral patterns, concerning visual attention and perception of PACE labels on real products, this study used a head-mounted Tobii Pro Glasses 2 system. This system gains information at a sampling rate of 50 Hz and consists of a binocular corneal reflection and dark pupil tracking to guarantee an absolute pupil measurement during the recording time. The head unit of the glasses consists of four eye cameras and one wide-angle HD-scene camera at the front. It has a resolution of 1920 × 1080 pixels and a frame rate of 25 frames per second. The front camera records at a maximum angle of 82° horizontally and 52° vertically. The system is mounted as regular glasses, which enables natural viewing behavior in real-world environments. In this study, we were interested in the detailed visual information processing of the PACE labels on different products, which is why we focused on participant fixations. Furthermore, the PACE labels can be considered bottom-up factors, as we expect them to attract the attention of consumers. Since the labels are not available on the market, they are unknown to consumers. As the participants were not given direct/specific search orders, but were asked to pursue a snack-choice in a buying situation, it can be assumed that various top-down factors would direct their visual attentions. For example, the search for products that are healthy, for a specific brand or a drink, instead of a snack alongside the applied PACE label information.

Participants

A total of 102 subjects were recruited to take part in this study. The eye-tracking experiment took place at a German university in February 2019. The study was conducted in accordance with the Declaration of Helsinki and with the principles of the ICC/ESOMAR Code. Our study did not impose unreasonable stress to the participants nor did it harm their bodily or psychological well-beings. All participants provided written informed consent to take part and were informed about the opportunity to withdraw from the study at any point in time. They received a monetary compensation for the time allowance (around 20 minutes/assessment) at the end of the study (EUR 5.00). Before the experiment started, all participants received instructions about the testing procedure, had the possibility to ask questions, and were informed that they could withdraw from the study at any time without consequences. A total of 11 participants had to be excluded due to poor data quality of the eye-tracking measurement (cut-off value < 80% data quality). Therefore, data analysis was performed with 91 recordings. A total of 52 participants were female, and 39 were male. The mean age was 26.4 years (ranging from 18 to 40 years), and the average body mass index (BMI) was 22.58, ranging from a minimum of 16.8 to a maximum of 32.6.

Stimuli and Experimental Setup

The PACE label consisted of a blue symbol of a person running, with accompanying information on the physical activity calorie equivalent. We used a circular symbol of a person running, combined with a rectangular text field. It indicated the time it would take to complete a physical activity (in this case, jogging) to burn the equivalent number of calories of the particular product. The reference text on the claims translated into English reads as follows: *"To burn the calories of this product, you have to run for ...minutes."* The color of the symbol, as well as the label frame, was blue, because we focused on a more neutral color than green and red, as these are often associated with health/organic (green) or ban/warning (red) (Cabrera et al., 2017). The label was designed purely for this study and was added to all products of the supermarket store, by a specific label-sticker. To depict a real-life scenario, with close to real-life label sizes, we chose the size of the PACE labels according to the size of the product packages, and tried to make them appear as realistic as they would in real-life. The labels measured 4.5 × 1.5 cm (respectively 2 cm at the highest point). An exemplary illustration of the PACE label is shown in Figure 1.

Figure 1: Design of the physical activity calorie equivalent (PACE) label used in the eye-tracking (ET) experiment. The reference text on the claims translated into English reads as follows: “To burn the calories of this product, you have to run for … minutes.”

The PACE labels were printed and applied by the means of small stickers, and all of them were then attached onto a variety of 20 different snacks and soft drinks. All products were labeled with their respective PACE label based on the number of calories contained in the product. We used an online calorie tracker to convert the number of calories into physical activity and calculated the label values under the assumption that a person with a body weight of 70 kg burned 280 kcals when jogging slowly for 30 min (see also www.fitforfun.de, caloric calculator). We then rounded the exercise values (declared on the label) up or down so that they were shown in five-minute increments on the labels. The values ranged from 0 min to a maximum value of 60 min. All products were purchased at a German supermarket and, hence, were already available; there were no hypothetical products. The product selection was based on a thorough discussion, and pretesting within the research group of eight students and two principal investigators in charge. When selecting the products for this study, care was taken to create the widest possible range of popular soft drinks and snacks with different perceived health values. Market-leading manufacturers and a selection of organic products were included. Further, products with comparable calorie values, but different associated health values (‘healthy’ alternatives, such as fruit bars; ‘unhealthy’ alternatives, such as a chocolate bars) were selected. These included organic products, fruits, trail mixes, and drinks. By sorting the complex health values, we argued from a consumption perspective and balanced the healthy vs. unhealthy options (inspired by systematic design of choice experiments) to designate two groups with comparable mean number of minutes: mate tea, orange juice, water, banana, apple chips, oat biscuits, oat bar, fruit bar, trail mix, and peanuts in one group (= healthy snacks, mean: 27.5 min). The other group contained: Coke, Coke sugar free, energy drink, fruit juice drink, nut–nougat–crème snack, chocolate muesli bar, chocolate bar, chocolate biscuits, chocolate, and potato chips (= unhealthy snacks, mean: 26 min). Table 1 shows an overview of all selected products, their number of calories (per 100 g or ml and per product), the physical activity equivalent values in jogging units (per min), as well as the corresponding product prices.

Table 1: List of products with their calorie contents, equivalent values in jogging units, and the product price. The order of the products within the two groups (healthy vs. unhealthy) depicts the pairs described.

Products	Brand	Label	Calories per Product Unit (kcal)	Kcal per 100 g or ml	Kcal Equivalent in Jogging Minutes	Price in Euro
Healthy snacks						
Water, medium	Vio, medium	0 min	0	0	0	1
Orange juice	Hohes C	10 min	87.4	43.7	9.37	0.5
Mate tea	Club Mate	10 min	100	20	10.71	1.5
Fruit bar	Alnatura	15 min	135	338	14.15	0.5
Banana	-	15 min	115	89	12.32	0.5
Apple chips	Alnatura	25 min	213	356	22.82	1
Oat bar	Alnatura	30 min	276	406	29.58	1
Peanuts	Rapunzel	50 min	465.75	621	49.91	1
Trail mix	Seeberger	60 min	595	476	63.77	1.5
Oat biscuits	Bohlsener Mühle	60 min	596.25	477	63.9	1
Unhealthy snacks						
Coke, sugar-free	Coca Cola Zero	0 min	0	0	0	1
Fruit juice drink	Capri Sun	10 min	80	40	8.57	0.5
Energy drink	Red Bull	15 min	115	46	12.3	1.5
Chocolate muesli bar	Corny	15 min	114	455	12.21	0.5
Chocolate bar	Kinder Country	15 min	132	561	14.14	0.5
Coke	Coca Cola	25 min	210	42	22.5	1
Nut–nougat–crème snack	Nutella To Go	30 min	266	511	28.51	1
Potato chips	Funny-Frisch	30 min	265	530	28.4	1
Chocolate	Milka	60 min	530	530	56.8	1
Chocolate biscuits	Leibniz	60 min	610	488	63.89	1

To simulate a supermarket situation, all products were placed on a shelf as in a real shopping situation (see Figure 2). All products were arranged in multiple rows, so that it looked similar to a supermarket shelf. Since it was aimed to simulate a real purchase situation, price information was attached to the front of the shelves. The prices ranged from EUR 0.50 to EUR 1.50 in increments of EUR 0.50 and were within the typical price range for these product categories in Germany, which had previously been validated through an inventory in different shops. The prices had been rounded up/down to simplify the purchase process. The shelf, the positioning of the products, as well as the pricing information, are shown in Figure 2.

Figure 2: Setup of the snack shelf in the laboratory supermarket during the eye-tracking experiment.

Study Procedure

The experiment took place in a laboratory room at a university located in Germany. It contained no furniture or wall decorations other than a table and chair for the subject, as well as the prepared product shelf that including 20 different snacks and soft drinks, and a black board for the calibration of the eye-tracker. To ensure constant lighting conditions, the window front was shielded. After providing general instructions about the experimental setting, the test persons were informed about the methodical processes and the test procedure. Then, the eye-tracking glasses were given to the participant, with instructions to wear them like normal glasses. The use of the eye-tracker was not affected by the presence of a visual aid and could simply be placed over normal glasses. To calibrate the eye-tracking glasses, participants had to look at the black billboard, where a calibration template was attached to the middle of the black background. Due to the head-mounted glasses used in this study, the participants were not restricted in their movements, which enabled them to behave naturally when looking at the shelves, when taking the products off to read the information on the back, and so on.

Participants received the following instructions concerning their task: *"We have set up a small test supermarket for you. Take your time and look at the products. If a snack appeals to you, please select it. After the experiment is completely finished, you will receive the monetary compensation and pay for the snack at the checkout. Your selection is binding. Please start* *shopping in our supermarket now."* Participants were not forced to select and buy products. A choice was made when they grabbed the product(s) and informed the test supervisor that they finished their purchase. There was no limit in terms of the number of products to purchase. After the participants had chosen a product, the recording was stopped, and the eye-tracking glasses were removed. Immediately following the end of the ET experiment, the participants were asked to fill in a questionnaire, which contained general questions about the food, sleep, and movement behaviors of participants. In it, the first three questions were open questions, aimed to discover whether the participants recognized the PACE labels, and what information they were looking for on the products. In the end, the chosen product was paid; participants received monetary incentive and could keep the chosen product(s).

Data Analysis

The analyses of eye-tracking data were performed with the software Tobii Pro Lab x64 (version 1.111.19220; Tobii Technology, Stockholm, Sweden). The datum used to analyze was a picture taken of the shopping shelf, as shown in Figure 2. Static area of interest (AOI) was defined for each product as a whole, another AOI covered the PACE label on the specific product. In addition, each price label in front of the product received an AOI (for the AOIs, see Figure 3). The label and price AOIs were almost consistent, in terms of size and shape. Due to the different sizes and shapes of the real products and the resulting optical differences on the photo used as a snapshot, there were smaller deviations (in millimeters) in the size of the AOIs. It is assumed that these deviations hardly influenced the trends in label perceptions.

Figure 3: Static AOIs covering the PACE on every product and the price signs in front of the products.

Three eye-tracking metrics were used to analyze the visual attention on the AOIs: *Time to first fixation* (TTF): this is the time period from the onset of the stimuli to the first fixation of a specific AOI (in seconds). *Fixation count* (FC): this metric counts the number of fixations that the participant makes to one specific AOI during the recording. *Total fixation duration* (TFD): this describes the length of each single fixation within the AOI (in seconds). Univariate methods were used to show descriptive statistics about the participants and their gaze behaviors. This included mean gaze durations and proportions of participants gazing at an AOI. Single factor analysis of variance (ANOVA) was used to calculate differences between different groups of mean values, e.g., whether the mean values of the labels differed significantly from those of the prices and the products, in regards to TFD, FC, and TTF. All statistical analyses were performed with SPSS (IBM, SPSS Statistics 26) and MS Excel 2010. The evaluation of the open questions from the questionnaire was based on qualitative content analysis according to Mayring (Mayring, 2010).

Results

Sample Description

Table 2 describes the sociodemographic characteristics of the sample (N = 91). It must be mentioned that the participants were recruited at a university, which means that they were, for the most part, students and, therefore, not representative of the German population. The gender distribution in the survey showed a slightly higher proportion of women (sample: 57.1%, German population: 51.2% female) (DESTATIS, 2019). The average age of 26.4 years of the participants was about 18 years below the German average of 44.4 years (DESTATIS, 2019). Furthermore, 33.3% of the participants already had a university degree (German population: 15.6%), and it can be assumed that the majority were still in university. The population group enrolled in higher education was, therefore, clearly overrepresented in the present sample. Concerning the physical activity of the participants, the results showed that most participants recorded pursuing low- or medium-intense physical activity. More than 60% of participants performed low-intensity physical activity more than two hours a week. More than 60% of participants were active for more than one to two hours, or more than two hours a week (medium physical activity). More than half of the participants performed physical activity more than one to two hours, or more than two hours per week (high intensity), but almost 18% declared not to perform high intensity physical activity ever. The number of participants who recorded not performing physical activity at all, or less than one hour per week, was less than 10%.

Table 2: Sociodemographic characteristics of the sample (N = 91).

Characteristic	Description	Frequency	Percentage
Sex	Female	52	57.1%
	Male	39	42.9%
Age	18–24 years	37	40.7%
	25–30 years	39	42.8%
	31–36 years	8	8.8%
	37 years and older	7	7.7%
Educational Level	Without educational certificate	0	0
	Certificate of secondary education	0	0
	General certificate of secondary education	3	3.3%
	General qualification for university entrance	58	63.7%
	University degree	30	33.0%
Household size (*n* = 90)	Alone	21	23.1%
	With 1 other	28	30.8%
	With 2 others	21	23.1%
	With 3 others	7	7.7%
	With 4 others	2	2.2%
	With 5 others or more	11	12.1%
Employment	Full-time employment	1	1.1%
	Part-time employment	8	8.8%
	Student with part-time job	43	47.3%
	Student without part-time job	36	39.6%
	In apprenticeship	3	3.3%
Income	< EUR 600	21	23.1%
	EUR 600–899	36	39.6%
	EUR 900–1199	22	24.2%
	EUR 1200–1499	7	7.7%
	EUR 1500–1799	1	1.1%
	> EUR 1800	4	4.4%
Easy physical activity (=non sweating to slightly sweating) (*n* = 79)	Never	1	1.1%
	<1 h/week	8	8.7%
	1–2 h/week	9	9.8%
	>2 h/week	61	66.3%
Medium physical activity (slightly sweating) (*n* = 81)	Never	4	4.3%
	<1 h/week	21	22.8%
	1–2 h/week	23	25.0%
	>2 h/week	33	35.9%

Strong physical activity (heavily sweating) (n = 81)	Never	16	17.4%
	<1 h/week	15	16.3%
	1–2 h/week	20	21.7%
	>2 h/week	30	32.6%

Eye-Tracking Data

Heatmap

Figure 4 shows the absolute fixation duration and absolute fixation count of the snack shelf in a heatmap to provide a general overview and to visualize the view of the shelf as a whole. In our case, items that were viewed longer and more intensely compared to the other products were apple chips, oat biscuits, trail mix, and oat bars.

Figure 4: Heatmap of absolute fixation counts and absolute fixation duration.

Metrics

Overall, the average total time of interest duration, which is the length of time that the participants concentrated on the shelf, was 43.05 s (SD: 23.45 s). The average total recording duration was 71.07 s (SD: 34.37 s). Moreover, 79% of the participants viewed the AOIs of the products at least once for a total mean view time of 24.27 s. Moreover, 22.91% viewed the PACE label AOIs at least once for a total mean view time of 3.51 s. For the price signs, this holds true for 5.93% of the participants, with a total mean view time of 0.41 s.

Time to First Fixation

In general, the products had 71.88 fixations, whereas oat biscuits (89 times), trail mix (86 times), and apple chips (85 times) had the highest number of counts. The labels had on average 20.85 fixations, with oat biscuits (42 times) having the highest number of counts, followed by trail mix (34 times) and banana 1 (31 times). The prices had 5.33 fixations on average, with chocolate (10 times) and chocolate muesli bar and oat biscuits (each nine times) having the highest counts. The products were, on average, first fixated after 12 s, the price signs after 22.39

s, and the labels after 22.47 s. The products with the shortest time to first fixation were fruit juice drink 1 (5.82 s), apple chips (7.04 s), and trail mix (8.33 s). The labels that were fixated fastest were fruit juice drink 1 (10.17 s), Coke 2 (11.35 s), and energy drink (13.72 s). For the price signs, fruit juice drink (6.65 s), energy drink (9.11 s), and medium water (10.95 s) had the shortest time to first fixation. For details, see Table A1. The products as a whole were fixated significantly faster than the labels ($p \leq 0.001$) and the prices ($p \leq 0.001$); the labels and the prices did not differ significantly. A comparison among the AOIs of the product, label, and price, in relation to the different health value product groups, showed that the TFF did not differ between the healthy and unhealthy product alternatives, nor between their labels and price signs. However, a more detailed comparison between the price signs of the products with differing health values but with a comparable number of minutes (healthy products–low minutes vs. unhealthy products–low minutes, and healthy products–high minutes vs. unhealthy products–high minutes) showed that the price signs of the unhealthy–high minute products were observed significantly faster compared to the healthy–high minute products ($p \leq 0.05$).

Fixation Counts

The products that had the highest number of participants with at least one fixation on the AOI were oat biscuits (97.8%), trail mix (94.5%), and apple chips (93.4%). For the labels, this held true for oat biscuits (46.15%), trail mix (37.36%), and banana 1 (34.07%), for the price signs for chocolate (10.99%), followed by oat biscuits and the chocolate muesli bar (both 9.89%). On average, the products were fixated 3.3 times per participant, the labels 1.39, and the price signs 1.1 times. For the products, trail mix (6.66), apple chips (5.54), and oat biscuits (5.1) had the highest number of fixations. For the labels, trail mix (1.88), energy drink (1.81), and chocolate bar (1.8), and for the price signs, apple chips (1.5), chocolate (1.3), and chocolate bar (1.25) had the highest number of fixations. For details, see Table A2. The products had a significantly higher number of fixations compared to the labels ($p \leq 0.001$) and compared to the prices ($p \leq 0.001$); further, the labels had a significantly higher number of fixations compared to the price signs ($p \leq 0.001$). When it came to the comparison of the different health value product groups, the AOIs of the healthier products had a significantly higher number of fixations ($p \leq 0.05$) compared to the unhealthy product group. There were no significant differences between the price signs and labels of these two groups.

Total Fixation Duration

The average total fixation duration for the products was 1.1 s, for the labels 0.5 s, and for the prices 0.31 s. The participants fixated on trail mix (2.34 s), oat biscuits (1.79 s), and apple chips

(1.75 s) the longest. For the labels, the ones of oat bar (1.04 s), trail mix (1.01 s), and Coke 1 (0.84 s) were fixated the longest, for the prices, the ones of apple chips (0.59 s), chocolate muesli bar (0.48 s), and Coke sugar-free (0.47 s). For details, please refer to Table A3. The products were observed significantly longer than the labels ($p \leq 0.001$) and then the prices ($p \leq 0.001$); further, the labels were observed significantly longer than the prices ($p \leq 0.001$). In regards to a comparison of the different health value product groups, the AOIs of the healthier products were observed significantly longer than those of the unhealthier alternatives ($p \leq 0.01$); their price signs and labels showed no significant differences. A more detailed comparison between the products with differing health values but with a comparable number of minutes (healthy products–low minutes vs. unhealthy products–low minutes and healthy products–high minutes vs. unhealthy products–high minutes) showed that the healthy products with the low minutes were observed significantly longer compared to their unhealthy alternatives ($p \leq 0.05$). This was also true for the healthy products with high minutes ($p \leq 0.001$); they were observed significantly longer and more intensely compared to their unhealthy alternatives.

Sociodemographic Gaze Behavior

In regards to sociodemographic variables that might have influenced participants' gaze behavior, we investigated that the younger half of the participants (= less than 26 years, mean age = 22.9 years) fixated the price signs earlier and faster ($p \leq 0.05$) than the older half of the participants (older than 26, mean age = 30 years). Further, men fixated the price signs significantly less often than women ($p \leq 0.05$). In regards to the movement behavior of the participants, we investigated differences between the group that reported higher activity levels ($n = 58$) and the group that reported less ($n = 33$). For the group that reported higher activity levels, the results showed a quicker response (time to first fixation) to the products as well as to the labels (products: $p \leq 0.05$, labels: $p \leq 0.001$), and a shorter fixation duration of the labels ($p \leq 0.05$).

The Product Choice

The results of the selected products are shown in Table 3. In total, 162 products were chosen because multiple choices were possible, without limitation (similar to a real scenario). The most frequently chosen products were bananas (24x), water (14x), mate tea (13x), and trail mix (13x). All of these products were in the group with a perceived higher health value. We asked participants whether their choice corresponded to the choices they often made in everyday life. Here, 80.2% agreed, approximately 8% were unsure, and 12% disagreed. The participants were also asked whether the PACE labels influenced their purchase decision. A total of 12.1%

agreed, 78% disagreed, and almost 10% were unsure. In contrast, when participants were asked whether the product price influenced their purchase decision, 50.5% agreed, almost 10% were unsure, and 38% disagreed. In regards to the two groups with differing physical activity, it can be seen that, in the group that was physically more active, 63.8% of the products purchased were from the group with healthier products, whereas in the group with the less physically active participants 75.8% of the products purchased were from the healthy product group.

Table 3: Frequency and percentage of the chosen products.

Product	Frequency	Percentage
Banana	24	26.4%
Water, medium	14	15.4%
Mate tea	13	14.3%
Trail mix	13	14.3%
Oat bar	11	12.1%
Chocolate bar	9	9.9%
Peanuts	8	8.8%
Chocolate	8	8.8%
Fruit bar	8	8.8%
Coke	7	7.7%
Apple chips	6	6.6%
Fruit juice drink	6	6.6%
Chocolate biscuits	6	6.6%
No product	6	6.6%
Oat biscuits	5	5.5%
Orange juice	5	5.5%
Nut–nougat–creme snack	5	5.5%
Potato chips	4	4.4%
Coke sugar-free	2	2.2%
Chocolate muesli bar	2	2.2%
Energy drink	0	0.0%

Note: multiple selections were possible. Bold letters represent the healthy products, normal letters the unhealthy one. The no-buy option is printed in italic letters.

Open Questions

With three open questions, we aimed to find out whether the participants recognized the PACE labels and what information they were looking for on the products. For the first question: “What did you look for when purchasing snacks?” we classified from the participants’ answers 206 content aspects into eight categories. Nearly 20% of the participants mentioned that they were looking for information about the product (e.g., origin, product appearance, etc.) or for price information. Moreover, 18% of the participants provided answers that we classified as product range (e.g., categories, variety, range arrangement, etc.), nearly 17% reported on their actual preferences and needs (e.g., food vs. drinks), and nearly 9% were looking for the health value of a product. Further, we classified a category dealing with answers concerning ingredients (8.25%), search criteria (5.34%), and the PACE label (2.91%).

For the second question: “Did you notice or remember anything special?” we classified 167 content aspects into six different categories, with half of the aspects being classified into the category product range (50.9%) (e.g., single products, product choice, etc.). Nearly 15% of the answers dealt with the product placement (e.g., shelf, setup, etc.), nearly 12% with the price and price comparisons, and nearly 9% with the health value of the products. Further, 8% indicated that they noticed the PACE label, whereas 6% mentioned that they did not notice or remember anything special.

For the third question: “What were you looking at or searching for?” we classified 190 content aspects, and identified two main categories, which were “snack motives” (67.37%) and “product features” (32.63%). To obtain a better understanding of what participants were specifically looking for, we also reported several subcategories of these two motives. The main “snack motives” were looking for healthy products and personal (taste) preferences (both 13.16%), followed by a small snack for in between (11.05%), drinks (9.47%), and sweets (8.97%). Two other motives were “snacks/foods that wake me up and give me energy” (6.84%) as well as “foodstuff that keeps me satiated for a long time” (4.74%). The category “product feature” highlighted which specific products from the product range the participants were looking for (13.16%), and what ingredients or special product characteristics were important to them (11.58%); moreover, some of them were looking for prices (5.79%) and for the PACE labels (2.11%).

Discussion

The purpose of this study was to obtain a better understanding of consumer perceptions of PACE labels, on a variety of real snack products, and the attention they received in a simulated food purchase setting. The special feature of this study was the application of a head-mounted eye-tracker system that allowed the participants to move freely, pick products off a shelf, and inspect the packages on their own initiatives, instead of being provided with images on a computer screen.

In regards to the perception of PACE labels, our eye-tracking data showed that the PACE labels in this study were looked at longer and more intensely compared to the price labels of the products. This is in line with other studies that showed that participants needed more time to perceive the labels, because processing the pricing information is easier than processing the more complex product information label, especially because price information is familiar to people and, therefore, does not attract much attention, whereas PACE labels are something individuals do not know about (Chandon, Hutchinson, & Bradlow, 2009; Huddleston, Behe, Minahan, & Fernandez, 2015).

We observed large differences in terms of the visual attention for the PACE labels on different products, which is reflected in a high standard deviation of all three metrics (TFD: mean: 0.55 s, SD: 0.57; TTF: mean: 22.46 s, SD: 18.9; FC: mean: 1.39 s, SD: 0.73). This is in line with another study that used real products and a head-mounted eye-tracker as well and found that the visual attention for labels varied between different label claims on different product categories (Steinhauser, Janssen, & Hamm, 2019). One explanation for the differences in this study might be the wide range of offered products. Despite the fact that we included products based on market availability, as well as health, we did not control for individual familiarity of all products (e.g., the organic products). As consumers tend to look longer at novel items (Meißner & Decker, 2010; van Herpen & Trijp, 2011), the novelty of some of the products and of the label (at individual respondent levels) per se could have led to the very different observation patterns. However, the sample size of 91 participants with a product choice of 162 was high, allowing for enough statistical variety among the participants and products to allow answering the main research questions, in regards to effectiveness and awareness of the PACE labels.

In regards to the health value of the products, the healthier products were observed significantly longer than those of the unhealthier alternatives; however, there was no significant difference between the fixations of their labels. One explanation for this might be that we did not specifically ask participants to choose healthy products, so they were not specifically looking for or using the support of a label to classify the products. Since we did not ask the participants what to look for specifically, the variety between the possible individual “search goals” might have been very high. This would have been supported by the fact that we identified seven different snack motives (in total 67.37% of all answers) and four different product features/characteristics when the participants were asked what they were looking at or searching for. Furthermore, it seems that our subjects already had high levels of health interests. The participants were all university students, a segment of the population that demonstrates a relatively high interest in nutrition and nutrition labels (Parmenter, Waller, & Wardle, 2000). Moreover, according to the direct ratings, participants exercised on a relatively regular basis, and most had a normal BMI. This might support the assumption of a rather health conscious sample.

Moreover, the general choices participants made were rather healthy, although no specific “health” goal was set for the participants. Bananas were the most commonly chosen products, and they had one of the slowest times until entering the respective label AOI. One explanation for this might be that the participants were specifically looking for a specific snack or fruits and, thereby, were fixated on the banana. Proportionately late first fixations often indicate top–down perceptions, since subjects deliberately scan the test setup for certain pieces of information (Ares et al., 2013). It might have been the case here that consumer specific goals, e.g., healthiness or habits, influenced participant gaze behaviors to that point (Ladeira, Nardi, Santini, & Jardim, 2019). This is also supported by the direct reporting that indicated a search for “healthy products” (see above).

The group of participants that reported less physical activity looked later at the products and at the labels, but they looked more intensely at the labels. Additionally, this group purchased a larger percentage of products from the healthy product group. Higher fixation durations are associated with an increased probability of purchase, and because attention mediates the effect of nutrition labels on choice, products fixated most and longest have the highest likelihood of being chosen (Ballco, de-Magistris, & Caputo, 2019; Bialkova et al., 2014). This could explain the higher percentage of healthy products bought by this group. However, contrary to our results, other studies showed that people trying to lose weight viewed calorie information longer because they were actively seeking for information (Wolfson et al., 2017). Generally, it is known that more health-focused people are more willing to check labeling, because they are more interested in healthy behavior; however, this is not always effective in decreasing calorie information or leading to healthier choices (Fenko, Nicolaas, & Galetzka, 2018; Hartley, Keast, & Liem, 2019). One explanation for the present results could be that the used PACE labels were not directly perceived as a health-related label, but rather the movement instructions were in the foreground and were therefore not so much of interest to the group of subjects who already moved a lot anyway. The less active group however seemed to have used the labels, which supports the idea that labels should be easily and quickly understandable, providing information in an intuitive and highly visible way. Further, PACE labels may have unveiled already existing knowledge about healthy food choices, and most likely were included in the purchase choice, as the PACE labels were visually more important than the price, typically a very important product attribute. Hence, we conclude that the labels may be effective enough to “re-prime” (prime already existing information) and, in combination with a healthy product offer, lead to a more healthy product choice.

In regards to the general perception of the PACE label, 12% of the participants agreed that the PACE labels influenced their purchase decision, 8% indicated that they noticed the PACE label, and around 3% actively mentioned the use of the PACE labels when asked what they were looking for. At the same time, the average participant viewed the PACE label at least once on 22.9% of the products. Even though our labels were unknown to the participants, which could have increased the interest or attention to them, it seems that they did not attract a lot of direct attention. This is in line with other studies that showed that nutrition labels were not the most intensively viewed product information (van Herpen & Trijp, 2011). PACE labels, in a study by (Wolfson et al., 2017), achieved similar results; the average participant viewed the label on 17% of 64 nutrition fact labels. Other studies showed that nutrition labels were more likely to be used and viewed if health was generally important to the consumer or if consumers had special health goals already in mind (van Herpen & Trijp, 2011; Visschers, Hess, & Siegrist, 2010). If this holds true, it indicates that, due to the rather health conscious sample we had, the number of people who perceived or used such a label in real life could be much smaller. Nevertheless, the eye-tracking data suggest that the use of the labels may have been more impactful than the price. Using this as a set reference, being a decisive criteria, in turn, the PACE label and its effect may be very impactful, especially for people not very involved in healthier product choices.

Although only a very small proportion of the subjects mentioned that they recognized the PACE labels, and other participants reported that they did not notice the labels until they were explicitly asked about them in the ensuing questionnaire, it might have also been the case that the exposure to the PACE labels might have made people aware, priming them to choose healthier (although with our data, we cannot clarify this to the latest). This may have primed respondents to be healthy and push them toward healthy products, e.g., something that did not require much exercise to compensate for, such as the bananas, which were the only real fruit and scored rather low on the minutes, as well as water and mate tea, the second and third most purchased products. Nevertheless, the eye-tracking system is an indirect measurement system of consumers’ awareness; hence, despite the fact that we cannot probe “no-social-bias”, it is certainly less impactful than in sole questionnaire studies. Further studies could include a control group that is not exposed to the labels to clarify these aspects.

Strengths and Limitations

This study has a number of strengths: it stands out with a range of 20 different snack products under simulated real-world purchase conditions, offering an equal share of healthy and not-so-healthy snacks. The real-supermarket lab brought elements of realism into the study that were usually missing. Comparative studies were carried out under controlled conditions on a PC monitor, with a small number of products (usually 4–8 products; e.g., biscuits, yoghurts, soft drinks). This close-to-realistic environment with three-dimensional products and the head-mounted eye-tracker allowed us to examine human decision patterns in a natural environment, free from any constraints.

However, in regards to limitations, it must be mentioned that the set-up might have been affected by biases in regards to product placing, familiarity, and social desirability; however, we specifically used the indirect measurement of the eye-tracking system to combat social-response bias.

In regards to product placement, the product offers were not varied within subjects, which would have allowed controlling for patterns in gaze behavior e.g., people fixate from left to right and from top to bottom. This might have affected the product metrics to some point, because the products were observed longer and faster than the labels. Our placement was chosen to present the products as clearly as possible and distinctly from one another, but also to show them as realistic as a snack shelf. We analyzed the product placement and found it to be stable in regards to the awareness of the label and product category. The perception of the labels seems to not be (or only to a limited degree) influenced by this gaze patterns. As described, what was more important was the base level of information and physical activity in this regard. Further, we did not include a familiarity rating of the products at the individual respondent levels. Such a scale could enrich future studies in order to surely allocate the effect of familiarity in response to awareness. We also did not pretest the familiarity of the products we used and it might be that the participants looked longer at the rather novel or unfamiliar products, which makes it difficult to find out why products attracted participants' attention. Overall, however, we are confident to pursue enough statistical variety through the chosen 162 products within our 91 respondents, in order to stabilize effects of familiarity or product placement, to answer the main research questions. Nevertheless, we would recommend randomizing the order and placing, if study budget can be allocated.

The use of three-dimensional products in a natural environment is challenging because they complicate a standardized preparation of the AOIs, as well as of the shelf. We chose the size of the PACE labels according to the size of the product packages, and tried to make them appear as realistic as they would in real-life. However, for the smaller products, such as the fruit bar or chocolate bar, we had to find a compromise with the size of the label that had to be realistic, but also large enough to be captured by the eye-tracker. Hence the labels were slightly too big for the small packages, but were still imaginable in a real-life scenario.

Conclusions

The present study was a first approach to examine PACE labels on various real snack products, with differing health values, in a close-to-realistic environment. The results indicate that PACE labels were perceived and actively remembered by the participants. They were looked at longer and more intensely compared to the price labels, but less often and intense compared to the product itself. However, as other product labels, they did not attract a lot of direct attention. Further, healthier products attracted more attention than unhealthier products. Moreover, the general product choices were rather healthy. This indicates the need to combine consumers' processing information with the offers, which might have influenced their attention in regards to snack product choices, which is especially interesting for public health discussions.

Our results are interesting to the scientific and health communities, in regards to three key findings: (1) labels (as a means of health related information) can trigger more healthy buying behavior, especially for people not yet fully involved. (2) PACE labels, which reduce action-based information to simple, meaningful content (e.g., 'running' minutes) framed by a neutral tone (blue color) may be a meaningful pathway to combat non-communicable diseases and should be followed after. (3) We understand and discuss the effect of PACE labels in light of a re-priming (remember information, already known), and combine this with an action-based, easy to access hint (e.g., activity of xx minutes), as well as with a healthy product offer, which may be an important combination in order to improve public health.

Based on our results, one could additionally recommend being aware of different target groups that might use the label information in different ways; the capture of the labels through label size and product placement should be adjusted appropriately for people who are actively seeking assistance through labels. For this group, the PACE label may be the last tipping point to choose a healthier option, if healthy options are made available.

Our results also show that research in real-world settings is possible; therefore, we recommend continuing researching the influence of PACE labels on purchase behavior, with wider target groups, at best between-subjects, to better distinguish different experimental effects.

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Appendix

Table A1. Time to first fixation (TTF) (in seconds) and standard deviation (SD) of the products, the PACE label and the price in front of every product. Within the table, the data are sorted based on the minutes that were declared on the PACE label of the product.

AOI	Minutes on PACE Label	Time to First Fixation Product	SD	Time to First Fixation Label	SD	Time to First Fixation Price	SD
Coke sugar-free 1	0	13.63	17.21	18.87	14.76	49.53	46.41
Coke sugar-free 2	0	11.47	13.67	17.20	19.37	49.53	46.41
Water, medium 1	0	10.82	12.77	21.61	24.37	10.95	5.96
Water, medium 2	0	14.85	18.98	31.64	28.63	10.95	5.96
Mate tea	10	9.44	9.26	15.98	12.97	30.17	17.79
Orange juice 1	10	12.67	12.33	34.11	24.25	19.72	22.43
Orange juice 2	10	8.83	11.68	15.81	16.80	19.72	22.43
Fruit juice drink 1	10	5.82	7.55	10.17	11.48	6.65	5.18
Fruit juice drink 2	10	9.10	12.02	16.51	18.13	6.65	5.18
Fruit bar	15	16.37	14.18	26.65	23.06	11.50	4.13
Energy drink	15	11.92	13.00	13.72	14.39	9.11	9.37
Chocolate muesli bar	15	14.33	10.93	24.18	18.86	24.31	16.09
Banana 1	15	16.06	17.12	26.94	20.95	28.96	14.81
Banana 2	15	16.55	14.33	24.00	18.04	28.96	14.81
Chocolate bar	15	18.52	15.14	31.62	18.80	31.75	21.04
Apple chips	25	7.04	6.65	27.27	22.15	20.93	16.50
Coke 1	25	9.52	12.42	16.53	17.67	18.83	9.60
Coke 2	25	9.12	13.37	11.35	10.11	18.83	9.60
Potato chips	30	8.77	12.35	25.04	23.27	23.51	18.09
Nut-nougat-creme snack 1	30	14.13	12.82	24.36	17.62	19.34	14.80
Nut-nougat-creme snack 2	30	16.54	14.44	30.44	19.62	19.34	14.80
Oat bar	30	12.20	10.33	19.48	11.80	23.07	9.55
Peanuts	50	11.46	10.15	18.50	15.03	25.65	13.01
Trail mix	60	8.33	10.08	24.63	23.37	24.18	15.32
Oat biscuits	60	9.17	10.34	23.89	17.54	28.57	19.23
Chocolate	60	14.85	18.98	31.64	28.63	10.95	5.96

Chocolate biscuits	60	16.00	18.40	30.67	28.00	25.84	1.55
Average	-	11.99	12.76	22.47	18.98	22.37	14.90

Note: All products that were placed side-by-side received an individual AOI. Therefore, some products, such as the soft drinks, had two AOIs for the label. They are referred to as product 1 (the left product on the shelf) and product 2 (the right product on the shelf). The price label was placed between these two products, and similar products thus only had one price label. The TTF of the prices was therefore the same for product 1 and product 2.

Table A2. Number of fixations (FC) and standard deviation (SD) that the participants gave to the PACE labels, the products, and their prices. Within the table, the data are sorted based on the minutes that were declared on the PACE label of the product.

AOI	**Minutes on PACE Label**	**Fixation Count Product**	**SD**	**Fixation Count Label**	**SD**	**Fixation Count Price**	**SD**
Coke sugar-free 1	0	2.09	1.33	1.20	0.42	1.00	0.00
Coke sugar-free 2	0	2.30	2.09	1.19	0.68	1.00	0.00
Water, medium 1	0	2.87	2.19	1.50	1.10	1.17	0.41
Water, medium 2	0	2.67	2.15	1.71	0.99	1.17	0.41
Mate tea	10	3.96	3.18	1.21	0.41	1.00	0.00
Orange juice 1	10	1.98	1.58	1.07	0.27	1.13	0.35
Orange juice 2	10	2.58	1.53	1.26	0.56	1.13	0.35
Fruit juice drink 1	10	2.94	1.96	1.25	0.65	1.00	0.00
Fruit juice drink 2	10	3.07	1.84	1.14	0.48	1.00	0.00
Fruit bar	15	3.40	3.09	1.24	0.54	1.00	0.00
Energy drink	15	2.58	1.94	1.81	1.33	1.00	0.00
Chocolate muesli bar	15	2.64	2.85	1.17	0.38	1.00	0.00
Banana 1	15	3.07	1.84	1.45	0.96	1.20	0.45
Banana 2	15	3.51	3.02	1.60	1.13	1.20	0.45
Chocolate bar	15	2.76	2.12	1.80	0.89	1.25	0.50
Apple chips	25	5.54	4.80	1.27	0.59	1.50	0.55
Coke 1	25	2.84	2.00	1.69	1.14	1.00	0.00
Coke 2	25	2.53	1.63	1.00	0.00	1.00	0.00
Potato chips	30	4.66	3.67	1.38	0.77	1.14	0.38
Nut–nougat–creme snack 1	30	2.38	1.69	1.27	1.00	1.00	0.00
Nut–nougat–creme snack 2	30	2.26	1.76	1.39	0.61	1.00	0.00

Oat bar	30	4.04	3.50	1.70	1.36	1.00	0.00
Peanuts	50	3.98	3.11	1.09	0.30	1.00	0.00
Trail mix	60	6.66	5.58	1.88	1.20	1.17	0.41
Oat biscuits	60	5.10	3.94	1.48	0.92	1.11	0.33
Chocolate	60	3.35	2.21	1.29	0.59	1.30	0.67
Chocolate biscuits	60	3.95	2.65	1.50	0.65	1.00	0.00
Average	-	3.32	2.60	1.39	0.74	1.09	0.20

Note: All products that were placed side-by-side received an individual AOI. Therefore, some products, such as the soft drinks, had two AOIs for the label. They are referred to as product 1 (the left product on the shelf) and product 2 (the right product on the shelf). The price label was placed between these two products, and similar products thus only had one price label. The FC of the prices was therefore the same for product 1 and product 2.

Table A3. Total fixation duration (TFD) and standard deviation (SD) of the products, the PACE labels and the price signs (in seconds). Within the table, the data are sorted based on the minutes that were declared on the PACE label of the product.

AOI	**Minutes on PACE Label**	**Total Fixation Duration Product**	**SD**	**Total Fixation Duration Label**	**SD**	**Total Fixation Duration Price**	**SD**
Coke sugar-free 1	0	0.69	0.65	0.66	0.86	0.47	0.03
Coke sugar-free 2	0	0.88	0.91	0.47	0.52	0.47	0.03
Water, medium 1	0	0.82	0.80	0.74	1.12	0.29	0.16
Water, medium 2	0	1.01	1.08	0.75	0.59	0.29	0.16
Mate tea	10	1.29	1.27	0.39	0.35	0.35	0.13
Orange juice 1	10	0.77	0.92	0.35	0.29	0.39	0.29
Orange juice 2	10	0.84	0.67	0.46	0.44	0.39	0.29
Fruit juice drink 1	10	0.87	0.75	0.54	0.66	0.23	0.15
Fruit juice drink 2	10	0.89	0.62	0.42	0.29	0.23	0.15
Fruit bar	15	1.13	1.39	0.55	0.68	0.23	0.01
Energy drink	15	0.77	0.78	0.55	0.68	0.20	0.03
Chocolate muesli bar	15	0.84	1.02	0.45	0.32	0.48	0.27
Banana 1	15	1.02	1.28	0.34	0.66	0.24	0.07
Banana 2	15	1.27	1.54	0.66	0.56	0.24	0.07
Chocolate bar	15	0.90	0.78	0.48	0.40	0.24	0.07
Apple chips	25	1.75	1.73	0.45	0.35	0.59	0.29

Coke 1	25	0.87	0.87	0.84	0.84	0.30	0.13
Coke 2	25	0.67	0.60	0.33	0.19	0.30	0.13
Potato chips	30	1.42	2.60	0.50	0.65	0.36	0.31
Nut–nougat–creme snack 1	30	0.72	0.71	0.51	0.60	0.20	0.13
Nut–nougat–creme snack 2	30	0.67	0.73	0.45	0.41	0.20	0.13
Oat bar	30	1.71	2.11	1.04	1.27	0.17	0.09
Peanuts	50	1.39	1.28	0.28	0.11	0.21	0.03
Trail mix	60	2.34	2.48	1.01	0.90	0.29	0.08
Oat biscuits	60	1.79	1.76	0.63	0.64	0.46	0.36
Chocolate	60	1.05	0.85	0.61	0.79	0.44	0.21
Chocolate biscuits	60	1.25	1.22	0.48	0.29	0.22	0.06
Average	-	1.10	1.16	0.55	0.56	0.31	0.15

Note: All products that were placed side-by-side received an individual AOI. Therefore, some products, such as the soft drinks, had two AOIs for the label. They are referred to as product 1 (the left product on the shelf) and product 2 (the right product on the shelf). The price label was placed between these two products, and similar products thus only had one price label. The TFD of the prices was therefore the same for product 1 and product 2.

5 General Discussion, Conclusions and Implications

This work offers implications for future fields of action not only on a scientific but also on a practical level. These are highlighted in the following and supplemented by a research outlook.

5.1 Scientific Implications

Advancing consumer neuroscience – the challenge of mobile methodologies and real-life experiments:

Looking at the results presented in this thesis under the premise of the mobile methodologies used, it can be stated that the integration and use of fNIRS and ET contributed to the methodological development of CN. This outcome results from the application of a variety of empirical approaches that used realistic stimulus presentations in more real-life-oriented experiments from different food marketing contexts and, as such, increased the ecological validity.

The articles show that mobile methodologies allow more realistic experiments, e.g., with realistic gustatory stimuli (A1 and A4), in close-to realistic environments (A5), with real products as experimental stimuli (A2, A3, A5), and generally under more realistic conditions. Applying mobile CN tools allowed for a more normal behavior of the participants. They could walk/drink/eat/behave almost freely and normally and were not or only partly limited in their movements (in A3 and A4, participants were asked to avoid strong head movements). This allowed for the collection of data otherwise difficult to acquire. Unconsciously occurring neural processes during the perception of differently framed labels (A2 and A3), the emotional processing of marketing-related messages (A2 and A3), the neural reflection of different taste nuances (A4), and consumers' perception of and visual attention to different health-related messages and labels (A3 and A5) in realistic environmental settings and at the point where decision-making behavior takes place (A5) are only some examples of what has been achieved in the presented articles.

As such, the articles presented here are a first step towards applying mobile neuroscientific tools for research questions from food marketing, and to test whether experiments under more realistic circumstances can bring additional value to CN. They highlight the general importance of real-life studies: In an applied research field, such as food and nutrition marketing where one wants to use neuroimaging to study multisensory stimuli, it is not sufficient to use stationary methods and carefully controlled laboratory experiments (Meyerding & Mehlhose, 2020; Brouwer, Zander, van Erp, Korteling, & Bronkhorst, 2015). This allows to investigate basic processes involved in decision making and to verify which neurophysiological measures are linked to emotions or mental states, but individuals behave differently in controlled lab environments than under realistic every-day circumstances (Brouwer et al., 2015). Therefore, real-life consumer behavior, e.g., in a natural (shopping) environment or with realistic presentations of gustatory stimuli, seems to be assessable.

However, A1–A4 show also that in the attempt to orient the experiments more towards real-life scenarios, it is not always possible to meet all requirements to directly draw conclusions about underlying mental processes. The challenge is that comparably reliable information from neuroimaging is expected when there are no distractions or artefacts from body movements and when a lot of data is available (Brouwer et al., 2015). As mobile methods do not restrict the subjects in their movement behavior, spontaneous reactions, e.g., body or head movements, can occur. Due to these resulting confounds in real-life studies (e.g., motion artefacts, external influences), it is more challenging to connect neurophysiological results from real-life examinations directly to underlying cognitive or affective states (Brouwer et al., 2015; Meyerding & Mehlhose, 2020). Additionally, relatively reliable information can be expected when the relationship between neurophysiology and the mental state of interest is clear and well estimated, and the experimental design is based on a theory, so that it can be administered by direct stimulation of the associated neurophysiological signals (Brouwer et al., 2015; Plassmann et al., 2015). However, exploratory studies, as presented in the articles here, cannot always use a theory-driven approach for designing studies, because in CN, mental processes and underlying brain functions are much less understood until now (Mehlhose & Risius, 2020). This makes it more challenging to state causes and effects without falling into the trap of reverse inference (= inferring from the neural signal to the mental process instead of vice versa, described in more detail in A1) (Plassmann et al., 2012; Plassmann et al., 2015). This highlights the need for more research where clear distinctions are made between what can be really concluded from the results and what may only eventually be possible (Brouwer et al., 2015; Cacioppo, Cacioppo, & Petty, 2018).

Concluding from this and looking ahead, it needs to be shown that the application of neuroscientific methodologies is justified in the sense that it provides data or information that is otherwise not achievable and that creates some sort of new or unique knowledge (Lee et al., 2018). Neuroscientific tools should only be used to measure items that go beyond what is possible with traditional tools. They should not be used, e.g., for the examination of liking (can be easily met with a Likert scale in a survey), but rather to better understand the underlying constructs that might lead to a liking (e.g., reward) (Niedziela & Ambroze, 2020). CN does not have the claim and will not be able to replace traditional marketing instruments (Plassmann et al., 2015; Solnais et al., 2013). Instead, a combination and complementation of (mobile) CN methods, behavioral measurements, and traditional marketing instruments as shown, e.g., in the experiment in A4, will be essential to better understand consumer behavior and its different components, but also to have a better verification and validation of the neuroimaging results through the behavioral measurements that could and should support further connections with classical constructs of consumer research (Kenning et al., 2007; Solnais et al., 2013).

The special case of fNIRS – integrating fNIRS into the context of consumer neuroscience

Looking at the presented results, the integration and use of mobile fNIRS has revealed some decisive advantages compared to other neuroscientific methodologies, and its use can be justified by the fact that a wide range of marketing-related stimuli and questions can be investigated with it.

The articles show that neural PFC activity related to brands and labels can be measured with fNIRS. Also, they demonstrate the ability of fNIRS to capture processing through differently framed and primed labels in food contexts, e.g., when it comes to differences between the perception of e.g., strong vs. weak brands or positive vs. negative primes (A1–A3). Additionally, the articles present a first approach to link neural responses to underlying mental processes by tracing the PFC activity in relation to a health-labelling approach back to brain regions associated with reward evaluation and self-control (A3). To further increase the possible uses and applications for CN experiments, A4 extends the scope of fNIRS, transferring the application of fNIRS to the field of sensory science and taste perception. For this specific field, fNIRS has one major advantage compared to other neuroimaging methodologies: It allows for a natural and unrestricted stimulus presentation of gustatory stimuli. In our case, subjects were sitting at a table and a cup with a drink was given to them. They were able and allowed to take the sample independently, while in fMRI studies, the samples are pumped through a straw into the mouth of the lying and fixed subjects. Additionally, the article shows that the use of more objective methods for hedonic evaluations could be helpful to establish enhanced mechanisms of consumer sensory tests.

However, it also needs to be considered that due to disadvantages mentioned in chapter 2.5, fNIRS does not seem equally suitable for all situations and applications. The articles faced several issues: A4, e.g., examined whether and how two different taste nuances are reflected in the neuronal data of the subjects but could not detect a difference. This led to the assumption that differences in taste quality were not strong enough to be measured with fNIRS, or that other regions (not detectable with the fNIRS system) may be more important to assess the quality nuances. However, no conclusive explanation can be provided at this point, and further research should be carried out to further explore this issue. It also needs to be kept in mind that only superficial areas of the brain are measurable with fNIRS, which complicated the interpretation of the results, e.g., in A2 & A3, because only parts of the constructs of interest (e.g., reward system) were measurable. Future studies should be aware of the fact that fNIRS has a low spatial resolution and should therefore consider this when selecting possible mental processes to be investigated. fNIRS does not allow for the investigation or explanation of interconnected constructs or networks involving deeper brain layers, which would be, however, interesting for some consumer behavior-related constructs of interest.

To conclude, there is one very important advantage of integrating fNIRS as a CN tool, which is that fNIRS can be used to make neuroscientific investigations more realistic and diverse. Through the easier and less expensive fNIRS device, it is possible to increase the sample sizes up to n=100, as it was done in the A3 and A4, whereas regular neuroscience studies use n=25–30. Additionally, it is possible to integrate populations (e.g., overweight people as in A3) which cannot, or only to a limited extent, be investigated with other neuroscientific methods. The absence of restrictions regarding the subjects to be studied is an advantage that has hardly been used so far and should therefore be decisively strengthened in the future. Looking ahead, it would be worth considering not only the even greater inclusion of elderly people, but also that of children. Eating behavior and habits in particular are decisively shaped in childhood, and the fNIRS set-up is quite comfortable and very well tolerated even by young children (Nishiyori, 2016; Vanderwert & Nelson, 2014). Also, the examination of people with different socioeconomic backgrounds could provide interesting insights.

Consumer neuroscience for food and nutrition marketing

This section attempts to facilitate easy access for the use of this methodology in the field of food marketing, especially for researchers not coming from the field of neuroscience or psychology, and for whom it might be difficult to decide in which areas of consumer research for food marketing fNIRS can best be used.

The articles examine various different aspects of food marketing: A1 investigates the influence of the organic and the regional food label and the influence of strong and weak Coke brands on the PFC activity. This study pioneered in using fNIRS to test the effects and impacts of brands and labels on PFC activity and found that the labeled products led to a significant increase in neural PFC activity compared to non-labeled products. Apparently strong Coke brands led to an increase in PFC activation compared to apparently weak Coke brands, as the subjects did not notice they were drinking the same soft drink the entire time. This study showed the feasibility of fNIRS to achieve insights into consumers' brain activity related to brand and labels.

Then, A2 observed the neural reaction of differently framed food labels for products of animal origin, claiming the presence or absence of an additional quality aspect and under the impulse of emotional priming. An idyllic prime and a prime related to a label claiming an additional product quality led to increased PFC activity, which could indicate that the prime stressed the meaning of the label, in the sense that anchor frames regarding quality attributions should be positively phrased. As such, this study sheds light on which elements are of importance to identify products that meet consumers' requirements in terms of quality aspects.

CN tools were also used for aspects in health marketing, which was, e.g., a labelling approach with health warning messages on sweets in A3. Consumers' neural reactions to different graphical health warning messages (stop and shock symbols) were examined. In reaction to this, activations in brain regions associated with reward evaluation and self-control were found, indicating that fNIRS is able to detect emotional reactions evoked by rather disturbing health warning messages.

Then, in A4, the mobile fNIRS device was used for a sensory marketing approach. This examined whether and how two different taste nuances are reflected in the neuronal data of the subjects. No significant differences between two plant-based milk samples could be found, and all samples led to a decrease in neural activation. This indicates that fNIRS is generally able to study neural perception of taste, but further research is needed concerning the intensity of taste differences that can be detected.

Finally, in A5, an ET device was used to study consumer behavior in a real-world setting. PACE labels, a health-related labelling approach, and consumers' perception and their visual attention to them on real snack products were the objects of examination. The study found that PACE labels may facilitate healthier choices, especially for people with little exposure to health topics. It additionally shows that realistic study settings with real food products are possible.

Based on the articles presented here and referring to general CN literature that often demands, e.g., an extended range of methods used (Lee et al., 2018), the following section provides an outlook of what might be interesting research areas in the field of food and nutrition marketing for the specific use of fNIRS. It also highlights at which point the findings from the articles could be used as a starting point for this.

One option is to study the marketing placebo effect (MPE) with the help of fNIRS. A1 and A2 can be used as a starting point for this. The MPE is a well-known effect where a manipulation of an expectation concerning a product, evoked, e.g., through the appearance, brand, label, or price, influences the subjective perception of the product, e.g., its taste experience (Enax & Weber, 2015). It can be measured behaviorally and neuronally, but since consumers are not aware and therefore not able to report placebo effects, the demonstration and explanation of neural correlates of these effects would mean to get access to more detailed information about it (Plassmann & Weber, 2015). This information could be used to measure the effectiveness of a placebo marketing strategy in consumers (Ariely & Berns, 2010). CN studies have used, e.g., wine, and labelled it as more/less expensive. The neural activity was stronger when the subjects were told that they tasted the expensive wine. This correlated with their preference ratings for the wine, even though they drank the same wine the entire time (Plassmann et al., 2008). To the best of my knowledge, there are no real MPE studies conducted with fNIRS to date, but in light of the simpler set-up and the possibility to combine it with other methodologies, e.g., ET, this approach promises potential to better understand and utilize the impact of the MPE.

Another option is to use fNIRS to study food cues and food cue reactivity, especially in relation to healthy eating behaviors or in combination with nutritional intervention studies as proposed by Jackson & Kennedy (2013). A3 and A5 can be considered as a starting point for this. In the obesogenic food environment where we live today, our desire to eat is constantly stimulated. In the frequent consideration between rewarding food stimuli, on the one hand, and self-regulating control processes, on the other hand, many people face problems when trying to keep a balanced diet (Alonso-Alonso et al., 2015; Swinburn, Caterson, Seidell, & James, 2004). Since food cues and food cue reactivity seem to have different effects on overweight people than on normal weight people (Pursey et al., 2014; Stoeckel et al., 2008), but also on children compared to adults (Morys, García-García, & Dagher, 2020), it would be worth using the advantages of fNIRS concerning the absence of restrictions in the subjects to be studied, and to study the food cue reactivity of these special groups in real-world environments (Mehlhose & Risius 2020).

One promising application option is sensory research, for which A4 can be used as a starting point: The perception of flavor is a complex multisensory integration process. It provides several opportunities for neuroimaging to disentangle the sensory perceptions that subjects might not be able to report and which, as such, provide otherwise hidden data (Ariely & Berns, 2010). An important application of the fNIRS methodology could be to better understand how taste, odor, texture, or appearance all contribute to the gustatory experience and how they influence consumers in their food choices (Cherubino et al., 2019). Due to the advantages of fNIRS concerning realistic stimuli presentation and a relative tolerance concerning body movements, this holds great potential for future research.

A last option is to examine experiments with or in real-world settings, with A5 as a starting point. In the case of fNIRS, this could be, e.g., real-time measurements or measurements in unconstrained environments. The mobility and flexibility of the fNIRS technology should be used to study consumer behavior in action and to observe spontaneous brain activity in naturalistic environment settings, instead of waiting for the response of participants to stimuli. This could additionally change the focus from specific brain regions towards a new understanding of dynamic brain networks and should therefore be advanced further (Meyerding & Mehlhose, 2020). First approaches in this direction are the observation of neural activity while, e.g., being in a flight simulator, playing piano, driving a car, or doing sports (Balardin et al., 2017; Gateau et al., 2015; Yoshino, Oka, Yamamoto, Takahashi, & Kato, 2013). To the best of my knowledge, there are no such approaches from the food context so far. Conceivable would be, e.g., the real-time measurement while eating or while walking through a supermarket and doing grocery shopping. The decision-making moment is influenced by what consumers see, hear, smell, and touch, but people are not aware of these effects most of the time; thus, such an approach might offer data that is otherwise difficult to detect.

Against the background of the multitude of possibilities for studying food- and nutrition-related consumer behavior, scientists should feel encouraged to include fNIRS in their range of methods. For researchers considering the use of CN tools, it should be mentioned that the field is highly interdisciplinary by nature, which makes it, especially for newcomers to this field, very difficult to design, conduct, and evaluate studies correctly with respect to all their elements (Brouwer et al., 2015). It is challenging to keep the overview of the state of the art in all areas of expertise, but also to successfully integrate these methodologies into actual research or to evaluate the quality of research performed by others (Brouwer et al., 2015). Therefore, CN will benefit from multidisciplinary teams that define and set boundaries of what is possible and potentially helpful, and what is not (Brouwer et al., 2015). As existing literature on CN in general, but for application-related studies in particular, offers limited guidance on how to conduct strong neuromarketing research, greater user- and application-oriented methodological approaches for studies in real-life environments and with mobile methodologies would be very useful (Lee et al., 2018; Lim, 2018).

5.2 Practical Implications

The following section highlights the implications derived from the articles relevant for commercial applications.

Even though the articles presented here provide hope that there is generally great potential for commercial applications of neuroscientific tools for food-marketing related contexts, an extended use of these methodologies in the near future does not seem very likely and will be possible only to a limited extent. Neuromarketing and neuroimaging are currently not and will not in the near future be more cost effective than conventional marketing research methods, because the purchase of the equipment, the challenging process to design studies, and the expertise required are still major cost factors compared to the added value that can be achieved by using traditional methods (Ariely & Berns, 2010; Meyerding & Mehlhose, 2020).

However, one of the greatest advantages for the operational use of neuroscience instruments could lie in the technical advancement of the devices itself, which, as shown many times in the presented articles, have been expanded in terms of application possibilities through mobile devices that allow more cost-effective uses. Companies could realize, e.g., market research studies in which mobile devices complement traditional marketing research methodologies with the aim that more large-scale studies with more diverse target groups could provide better market forecasts.

Specifically, the greatest commercial potential for the use of fNIRS appears to lie at the level of product policy (Ariely & Berns, 2010). As intended in the articles, fNIRS could be suitable for capturing the perceptual processes and emotional processing of consumers in several situations and related to different product attributes (e.g., labels). Companies could use fNIRS when it comes to product development or product innovations to find out, on the one hand, which features influence the attractiveness of a product, which products have the greatest emotional impact or trigger positive feelings, and which attributes, on the other hand, cause aversion or negative feelings (Karmarkar & Plassmann, 2019; Kenning, 2014). In this way, the reward value of a product could be determined because, as shown in A3, the reward region of the brain seems to be partly ascertainable with fNIRS through an activation in the OFC. Other studies have already shown that the reward value allows a good prediction of the demand for a product or even for the success of marketing campaigns (Çakir, Çakar, Girisken, & Yurdakul, 2018; Gier, Strelow, & Krampe, 2020; Kühn, Strelow, & Gallinat, 2016). As such, the data accessible through CN could predict successful marketing campaigns or new innovative products, and the costs of applying CN tools would be outweighed by the utility of the increased revenues at the post-product stage, generating a more efficient trade-off between utility and costs (Meyerding & Mehlhose, 2020).

Additional possibilities include using a mobile ET device in product prototyping. This could help to investigate consumers' visual attention to different variants of products, product designs, or even marketing campaigns in a relatively uncomplicated way, similar to the approach presented in A5. It is probable, and we also observed this effect in A5, that longer-viewed products are more likely to be purchased (Ballco, de-Magistris, & Caputo, 2019; Bialkova et al., 2014). As such, prototpyes can be evaluated rapidly without the biases that often occur in subjective evaluation methods, and those concepts that are not satisfactory can be eliminated at an early stage in the product development process. Since many product campaigns in the marketing industry do not reach their goals, and high failure rates for new products are common, prototype testing could also be associated with significant cost savings compared to a failed market launch, which could have a decisive efficiency influence on the product design process (Ariely & Berns, 2010; Meyerding & Mehlhose, 2020).

To conclude and provide an outlook for marketers potentially interested in or already using CN tools as commercial applications, the aspect of social and ethical responsibility that the study of and with the human brain necessarily entails should be discussed at this point: In the public debate, the (commercial) use of CN is often associated with the possibility to gain insights into the subject's personality, which could threaten consumers' autonomy when it comes to the decision of buying/not buying a product (Cherubino et al., 2019; Javor et al., 2013). Even though continuing developments, such as fNIRS technology, for consumer research offer promising possibilities to reveal additional data about consumers' preferences, the possibilities for achieving such extensive and personal results are currently very limited (Meyerding & Mehlhose, 2020). Especially the fNIRS method is only able to compare relative differences in the oxygen concentration of certain brain areas at certain points in time. Absolute and therefore individual values cannot be measured with this method (Quaresima & Ferrari, 2016). Additionally, it is very important to mention that using CN tools does not mean finding the "buy-button" in the brain to help companies promote or sell the right products. What CN can do is to provide information to better understand consumers and to explain why they react the way they do (Cherubino et al., 2019). For real-world marketing applications, it might be even more interesting to use neural activity solely to predict future behavior but not to "influence" it (Ariely & Berns, 2010). However, marketers (and also scientists) should be aware that questions about whether neuroimaging technologies should be generally used outside of medicine and employed commercially, and whether the findings of neuromarketing research are representing a threat of individual consumer rights (e.g., privacy), are already the subject of discussions elsewhere (e.g. in Ariely & Berns (2010), Javor et al. (2013), and Murphy, Illes, & Reiner (2008)). It would be generally important that commercial but also non-commercial applications of CN adhere to high standards of science and address ethical concerns by conducting only experiments that are approved by an independent ethics committee and that comply with the Helsinki Declaration and the ethical principles for medical research on humans contained therein (WMA, 2013), and by following the Code of Ethics of the Neuromarketing Science & Business Association (NMSBA, 2013) and the ICC/ESOMAR International Code of Conduct for Market, Opinion and Social Research and Data Analytics (ICC/ESOMAR, 2016).

5.3 Concluding Remarks

Overall, this work clearly demonstrates that there is much potential for the application of mobile CN methodologies to examine consumer behavior in food marketing, even though the research is still at the very beginning. The integration and use of, e.g., fNIRS and ET, contributes to the methodological development of CN, as the articles in this thesis show that mobile methodologies present some decisive advantages compared to other neuroscientific tools: They allow for the examination of a variety of marketing stimuli, presented in more realistic and more natural ways, so that participants can behave quite normally. Additionally, these mobile methodologies have the potential to make neuroscientific investigations more realistic and diverse, because it becomes possible to examine larger sample sizes and to integrate population groups that cannot be investigated with fMRI (e.g., children, overweight people). As such, they increase the ecological validity of CN.

Scientists should feel encouraged to integrate mobile methodologies in their range of methods, because the real potential for CN lies in the complementation with traditional consumer research tools to provide data or information otherwise not attainable and that create some sort of new or unique knowledge, thereby increasing consumers' data variance. An extended use of these methodologies for commercial applications does not seem very likely at this time, because it will not be more cost effective in the near future than conventional marketing research methods. This work sees itself as a starting point for an increased use of mobile methodologies in consumer research and contributes to offering researchers from different disciplines ideas regarding possible research applications of fNIRS and CN in the field of food marketing. Building on the findings presented here, other works can hopefully further develop the use of CN methods in general and fNIRS in particular, thus advancing the research field of CN.

“New brain imaging technologies have motivated neuroeconomic studies of the internal order of the mind (...). We are only at the beginning of this enterprise, but its promise suggests a fundamental change in how we think, observe and model decision in all its contexts.”

- Vernon Smith –

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Can Neuromarketing Add Value to the Traditional Marketing Research? An Exemplary Experiment with Functional Near-Infrared Spectroscopy (fNIRS)

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Assessing Label Frames and Emotional Primes in the Context of Animal Rearing – Response of an Explorative fNIRS Study

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Neural Prefrontal Cortex Activation Resulting from Sensory Differences in Taste Tetected by Consumers of Plant-based Milk Alternatives – Neural Activation of Sensory Taste Differences

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PACE Labels on Healthy and Unhealthy Snack Products in a Laboratory Shopping Setting: Perception, Visual Attention, and Product Choice

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Formal declarations

1. Hiermit erkläre ich, dass diese Arbeit weder in gleicher noch in ähnlicher Form bereits anderen Prüfungsbehörden vorgelegen hat.

   Weiter erkläre ich, dass ich mich an keiner anderen Hochschule um einen Doktorgrad beworben habe.

Göttingen, 24.05.2022

Ort und Datum	Unterschrift

2. Hiermit erkläre ich eidesstattlich, dass diese Dissertation selbstständig und ohne unerlaubte Hilfe angefertigt wurde.

Göttingen, 24.05.2022

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