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OBJECT OR CAKE

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OBJECT OR CAKE? SELECTIVE PROCESSES IN
THE HUMAN BRAIN FOR THE RECENTLY
DISCOVERED SPECIALIZED FOOD AREA IN
THE VENTRAL VISUAL STREAM.

A Master's Thesis

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Ankara
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I certify that I have read this thesis and have found that it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Arts in Psychology.

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ABSTRACT

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The human ventral visual cortex shows category-selective organization to recognize and discriminate between ecologically important categories like faces, words, body parts, and places. The food image selective region in the ventral stream has been discovered by recent data-driven studies, which is called the ventral food stream. The overarching goal of this study is to investigate the ventral food stream by employing a novel object-food illusion: a hyper-realistic cake. In hyper-realistic cake videos, the initial object perception shifts to a perception of cake throughout the video. We conducted two different experiments. In Experiment 1, we collected behavioral data from 22 participants to validate the hyper-realistic cake videos. In Experiment 2, we first applied a functional localizer one-back task and employed validated object-food illusion videos with fMRI. Consistent with the recent findings of food selectivity, we identified the food-selective response in the ventral food stream by using a functional localizer task. During the video session, the ventral food stream exhibits a significant increase in activity when the object perception shifts to perception of a cake. Despite showing spatial variability between participants, there is a selective response to visual food cues in the fusiform cortex. This study shows the food-selective activity in the ventral visual cortex in

response to illusory visual stimuli in a hypothesis-driven manner. Future studies should conduct functional connectivity analysis to investigate how activity in the ventral food stream is correlated with activity in the gustatory cortices.

Keywords: Food selectivity, Ventral food stream, Category-selective organization, Object-food illusion



ÖZET

NESNE Mİ, YOKSA PASTA MI? İNSAN BEYNİNDE GÖRSEL VENTRAL AKIŞTAKİ SON ZAMANLARDA KEŞFEDİLEN YİYECEK RESİMLERİNE ÖZEL AKTİVASYON GÖSTEREN BÖLGENİN İNCELENMESİ

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İnsan beyninde günlük hayatta sıkça karşılaştığımız; yüz, kelime ve mekan gibi, kategorileri algılamak ve ayırt etmek için özelleşmiş seçici aktivasyon gösteren kategori-özellik bölgeleri bulunmaktadır. Son yıllarda birbirinden bağımsız yapıları veriye dayalı çalışmalar sonucunda görsel ventral yolak içerisinde yiyecek görsellerine özel aktivasyon gösteren bir bölge keşfedilmiştir ve bu bölge ventral yiyecek yolağı olarak adlandırılmıştır. Bu çalışmanın amacı yeni keşfedilen ventral yiyecek yolağını, nesne-yiyecek illüzyonuna sebep olan aşırı gerçekçi pasta videolarını kullanarak incelemektir. Aşırı gerçekçi pasta videolarında, başlangıçta algılanan nesne, nesnenin bıçak yardımıyla kesilmesiyle pasta algısına dönüşür.

Bu bağlamda iki ayrı deney gerçekleştirilmiştir. Birinci deneyde, aşırı gerçekçi pasta videolarının nesne-yiyecek illüzyonu olarak geçerliliğini değerlendirmek üzere 22 katılımcıdan davranışsal veri toplanmıştır. İkinci deneyde ise, öncelikle lokalize edici olarak bir geri-bir (one-back) görevi uygulanmış, ardından önceki deneyde geçerliliği doğrulanmış nesne-yiyecek illüzyonu videoları fonksiyonel manyetik rezonans görüntüleme (fMRI) sırasında gösterilmiştir. Önceki çalışmalarda rapor edilen yiyeceğe-

seici bulgularla tutarlı olarak, lokalize edici grev aracılıęıyla ventral yiyecek yolaęında belirgin bir yiyecek grsellerine seici aktivasyon tespit edilmiřtir. Video oturumu sırasında, nesne algısının kek algısına dnüştüęü anlarda ventral yiyecek yolaęında anlamlı bir aktivasyon artışı gözlemlenmiştir. Bu alışma, kuramsal bir yaklaşımla, illüzyon temelli grsel uyaranlara karşı ventral grsel kortekste gözlemlenen yiyecek-seici aktivasyonu ortaya koymaktadır. Gelecek alışmalarda, ventral yiyecek yolaęının tat duyususunu işleyen kortekslerle olan baęlantısını incelemek amacıyla işlevsel baęlantısallık analizlerinin yapılması önerilmektedir.

Anahtar Kelimeler: Grsel ventral yolak, Kategori seici aktivasyon, Yiyecek uyaranlarına seici aktivasyon, Nesne-yiyecek illüzyonu

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CHAPTER 1

INTRODUCTION

1.1 Category selective organization in the ventral visual stream.

How is the human brain organized? Do we have functionally specialized brain regions, or is each function processed across distributed brain regions? According to the functional localization account of the organization of the brain, the human brain is functionally organized into distinct modular cortical regions that are responsible for different functions, like language, motor, and vision (Weis et al., 2019; Op de Beeck et al., 2008). For instance, visual perception is accomplished by activity in specialized neural pathways depending on the visual information presented. After low-level visual features are processed in the primary visual cortex, neural signals travel to specialized pathways and regions for specific visual functions (Grill-Spector & Malach, 2004). Damage to these particular pathways or functionally selective regions may impair visual perception ability. For instance, damage to the occipital lobe, which is mostly responsible for vision, can result in partial blindness or visual agnosia, depending on the region and severity of the damage (Galetta, 2017).

Similar to the localized organizations of cognitive functions, the ventral visual cortex is organized into distinct brain regions for recognizing object categories of ecological importance. These categories include faces, body parts, scenes, objects, texts, tools, and foods (Epstein et al., 1999; Kanwisher et al., 1997; Peelen & Downing, 2017; Khosla et al., 2022; Emberson et al., 2017; Downing, Peelen, et al., 2006). Unlike other categories, food is a recent discovery by exploratory data-driven studies, and this finding is confirmed by later hypothesis-driven research. The category-selective regions in the occipitotemporal cortex not only get activated while people are viewing the selected category, like faces or scenes, but they also play an important role in

recognizing that category. For instance, in the case of damage to the Fusiform Face Area, which is selectively active while viewing faces, face recognition ability is impaired and causes prosopagnosia (Barton et al., 2002; Robotham et al., 2023). There is extensive research on the function of previously known categories like Fusiform Face Area (FFA), Parahippocampal Place Area (PPS), Extrastriate Body Area (EBA), and Visual Word Form Area (VWFA) (Grill-Spector & Weiner, 2014; Op de Beeck et al., 2019; Peelen & Downing, 2017). However, the recently discovered food-image selective region, the ventral food stream, needs further investigation to understand its functional importance and behavioral relevance. This study aims to investigate the neural response to the food-object illusion videos by using fMRI.

The details of the video stimuli presented in the experiment are explained later in the introduction and methods sections. However, to follow the introduction more smoothly, a brief explanation of the food-object illusion is provided here. The food-object illusion videos are so-called "hyper-realistic cake videos"; the video starts with a static object view, and during the video, the hand with a knife appears from either the left or right side of the screen and cuts the object smoothly, regardless of what the object is. After the knife cut, it is revealed that the object is actually made of cake. Thus, the initial object transforms into a cake during the video. In the scope of this master's thesis, two different studies were conducted; in Experiment 1, the aim was to validate the food-object illusion videos to be used in Experiment 2. To this end, the behavioral responses and ratings were collected in response to the hyper-realistic cake videos. In Experiment 2, two different tasks were applied during fMRI scans: (1) the functional localizer task to map the functionally specialized brain regions in the ventral visual cortex, and (2) passive viewing of hyper-realistic cake videos.

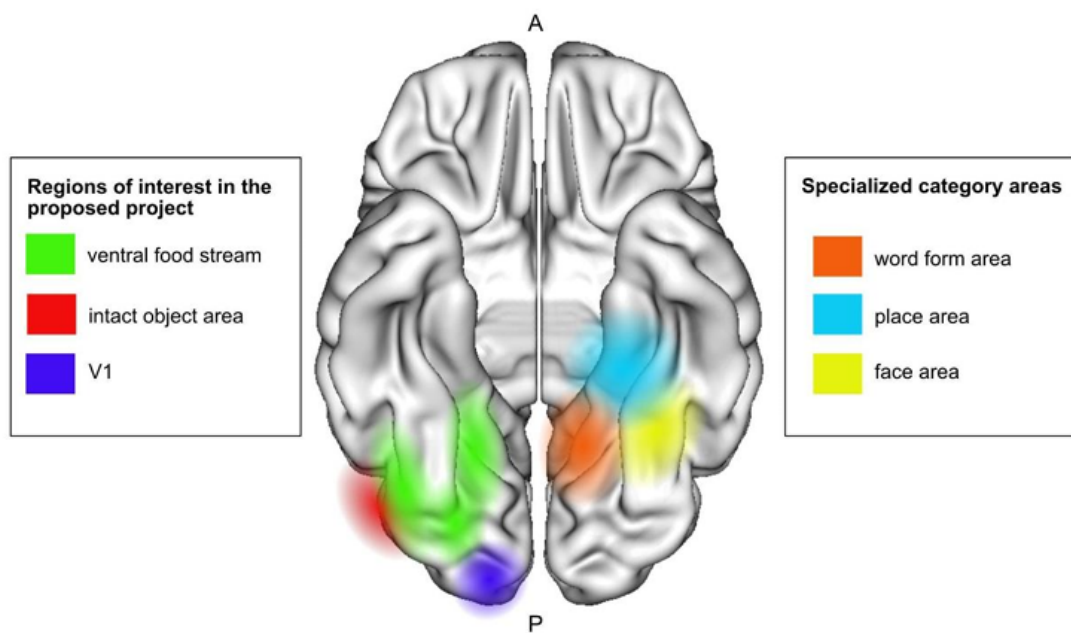


Figure 1: Approximate Locations of Category Selective Regions. The category-selective regions are located bilaterally, but for clarity, we displayed them on one hemisphere only. The green region represents the approximate location of the ventral food stream based on the recent findings. There is also possibly overlap between the ventral food stream and variation in the location of the ventral food stream.

1.2 Functional localization or distributed representation of object categories in the Ventral Visual Pathway.

Contrary to the functionally localized brain organization account, another account for the ventral visual cortex organization is that it is organized into the behaviorally relevant continuous dimensions, instead of concrete categories. During the initial years of functional neuroimaging with fMRI, the functional localization account of the ventral visual cortex organization became prevalent. The discovery of FFA, PPA, and EBA led to the understanding of functional specialization of the visual cortex in object recognition (Kanwisher et al., 1997; Grill-Spector et al., 2001; Downing, Chan, et al., 2006; Epstein & Kanwisher, 1998). However, after the improvement of the brain decoding methods like Multivariate Pattern Analysis (MVPA), it was revealed that there are distributed patterns of brain activity in the ventral visual cortex (Haxby et al., 2001). Whether the human ventral visual cortex is categorized into selective domains or shows a distributed pattern of brain responses to different behaviorally-relevant dimensions is discussed by several review articles (Op de Beeck et al., 2019, 2008). In a recent study, researchers paired human similarity judgments with the fMRI images of a variety of object images (Contier et al., 2024). Their model comparison between discrete categories and behaviorally-relevant dimensions showed that object dimensions explains variations in the data better than discrete object categories in the visual cortex. However, they also replicated the preferential activity to images of faces and places in the category-selective regions like FFA and PPA, relatively.

1.3 The new category-selective domain is: FOOD.

In this section, we will discuss the recent studies that revealed food-selective brain response patterns in the ventral visual stream. Khosla and colleagues applied a voxel decomposition method to the Natural Scenes Dataset without forming a specific

hypothesis to investigate the functional organization of the visual cortex (Khosla et al., 2022). While applying the voxel decomposition method, they created a voxel-by-stimuli matrix and decomposed it into two separate matrices: voxel-by-component and component-by-stimuli per participant. This method enabled them to investigate consistent brain patterns between participants. The Natural Scenes Dataset contains high-resolution fMRI data recorded while participants performed a recognition task while viewing thousands of naturalistic images (Allen et al., 2022). Their advanced hypothesis-free analysis confirmed the components that are selective for faces, scenes, words, and bodies. This finding supports the validity of the authors' analysis methods. In addition to identifying these components, they discovered a novel component that shows the third most consistent response between participants, after faces and scenes. That component is food. Medial and lateral to the Fusiform Face Area, they found two distinct regions showing selective responses to foods. To eliminate potential confounding factors, they controlled for low-level visual features like color, saturation, warmth, and shape. After they conducted a number of control analyses, the response pattern of the food component remained significant. Thus, the researchers concluded that food is the major contributing component of the response pattern in these regions, medial and lateral to the FFA. They called this region the 'ventral food component.' After the first publication on the ventral food stream by Khosla et al., two more articles that analyzed the Natural Scenes Dataset were published (Allen et al., 2022). Additionally, researchers found consistent food-selective activity in the ventral food stream by analyzing a THINGS database (Hebart et al., 2023). The second research study that used the NSD and confirmed the existence of food-selective response in the ventral visual cortex was conducted by Pennock et al (Pennock et al., 2023). They aimed to investigate the role of color-responsive brain regions and how color information is processed in relation to other image features. After they identified the color-sensitive regions in the ventral visual cortex, they realized that, among luminance, warmth, and circular objects, one of the common features of the images yielding the greatest voxel activity is food.

Independent of food, warmth and saturation are responsible for moderate variability in the neural response in the ROIs. Thus, the researchers concluded that the color-responsive regions in the ventral visual pathway are mainly food-selective and that color influences the voxel activity independent of food. The third research study was conducted by Jain et al., and they conducted two different experiments (Jain et al., 2023). The first one is data-driven, and they used the NSD, as previously mentioned in studies. They created a functional food localizer task for the second experiment and collected new data from four participants. Thus, it is both a data-driven and hypothesis-driven study. For the first experiment, the author's goal was to investigate food responsiveness in natural scenes. To this end, they generated labels for the commonly viewed thousand images in terms of their content, location, and perspective. Using a linear model, they identified regions that are more responsive to food images than other content labels. Consistent with the two previous findings, they identified two strips that are medial and lateral to the Fusiform Face Area. With several additional analyses, they confirmed that the primary category that is responsible for the variation in the brain responses in these stripes is food. For Experiment 2, they generated grayscale images of foods to create a food localizer in the visual cortex. In addition to the food pictures, they also included images of faces, scenes, body parts, and words. Thus, they identified the well-recorded category-selective regions like FFA, EBA, PPA, and VWFA. As a result of the localizer task, they identified the ventral food stream in response to food images, compatible with the result of the first experiment. Their finding also supports the Pennock et al. study in terms of finding food-selective responses in the absence of color information about foods. In a 4th data-driven study, researchers analyzed the THINGS database (Hebart et al., 2015). THINGS contains millions of images from various categories of objects, as well as judgments about the perceived similarity of those objects. The aim of this research is to determine whether object information is encoded based on discrete categories like face, body, food, and more, or whether it is represented based on continuous dimensions like animacy or semantics (Contier et al.,

2024). They mapped the tuning maps across 66 behavior-derived object dimensions, like head-related, child-related, outdoor, and food-related. When they compared whether categories or dimensions better explain the variances in brain responses, they found that object dimensions explain more variance than categories. These authors have identified the corresponding dimensions to well-known selective categories, such that the face-related dimension captures the FFA or the body-related dimension captures EBA. Consistent with the aforementioned data-driven studies, they also observed a ‘food-related’ dimension in areas near the fusiform gyrus, supporting the food-image representation in the occipitotemporal cortex. Like other categories, food is also represented by continuous dimensions, and in the case of food objects, one of those dimensions is the food-related dimension. Thus, the selective response to the food category in the ventral visual cortex is supported by independent research groups with different datasets. These four independent studies explained above found the distributed selective activity pattern for food around the same brain regions, which are the medial and lateral sides of the fusiform face area. Unlike the earliest fMRI studies of object representation in the brain, recent studies of object representation support multidimensional approaches for investigating category-selective brain regions, or category-selective activity patterns (Shehzad & McCarthy, 2018; Contier et al., 2024).

1.4 The emergence of category selectivity

How category-selectivity emerges, and why these regions develop where they do, are topics that have been questioned for years (Epstein et al., 1999; Grill-Spector et al., 1999; Kanwisher et al., 1997). Whether it is a result of a broad experience with the selected category or regardless of the experience, the human ventral visual cortex shows a preferential response to some categories, like faces, places, and bodies. To understand that, researchers conducted studies with infants and congenitally blind people. In a study conducted with infants between 2-9 months old, researchers found preferential activity to faces, places, and bodies in the domain-selective regions. So,

the authors suggested that substantial experience is not necessary to have domain-selective activity in the ventral visual cortex (Kosakowski et al., 2022). Also, studies conducted with congenitally blind people showed that, when congenitally blind people are presented with auditory stimuli corresponding to specific categories like faces or scenes, researchers observed that category-selective regions show preferential activity to the corresponding sound. Thus, these studies suggest that the development of domain-selective regions like FFA or PPA does not require visual exposure (Plaza et al., 2023; van den Hurk et al., 2017).

In a review that focuses on the critical factors where the category-selective regions appear, the authors suggested that the members of each category share common visual features, which is important for functional localization (Op de Beeck et al., 2019). For instance, places, even if they differ a lot, typically share standard features like containing a building with windows and doors and having vertical and horizontal lines. Another critical point is the relevance of the category to other cognitive issues. An image of a place is important for the classification of what that place is used for and how to act upon that place, so recognition of the building is important to understand the place. These accounts require visual experience, so considering the results from infants and congenitally blind people, there are different accounts for the organization of the category-selective regions in the ventral visual stream. Although there is no single view on how these regions emerged, the functional importance of these regions is predominantly agreed upon. So, what is the function of such specialization?

1.5 The Function of Category Selectivity in Ventral Visual Cortex

What would be the benefit of having specialized regions for processing information on faces, tools, bodies, scenes, texts, and also foods? What would be the function of such categorization of brain regions? The predominant view on the function of the

specialization of some visual categories is object recognition. Higher-order categorization helps recognize the subtle differences between different types of stimuli in the same category. For instance, face specialization is related to recognizing individuals (Tibbetts et al., 2024). Greater functional face selectivity has been found to be correlated with face recognition performance (Huang & Lee, 2009). Having a selective brain region for faces is linked to detecting the differences between each individual's faces and recognizing them, and that is essential for social connection. Quick and accurate identification of the detection in differences among faces is necessary for individual identification, so selectivity might be related to faster recognition of faces (Tibbetts et al., 2024). Another possible important function of categorical specialization is the region's connectivity to other brain networks that will serve behavior (Peelen & Downing, 2017). To initiate and maintain the visual representation, one needs to perceive the words or to maintain a stable and safe movement, one needs to be aware of the edges and scenes around. Thus, specialization provides better recognition of the category of importance. Also, perception can go wrong when these areas are not functioning normally. Lesion studies show what happens after damage to the domain-specific brain regions, such as the fusiform face area (FFA) and lateral occipital cortex. These studies provide an important source of information about the function of these regions. Patients with prosopagnosia and damage to FFA show an inability to detect changes in the positions of the facial features (Barton et al., 2002). Also, damage to a connected network with the right fusiform face area leads to prosopagnosia (Cohen et al., 2019). Another functionally important brain region for our study is the lateral occipital cortex (LOC). LOC is known to have an important role in object recognition (Grill-Spector et al., 2001). LOC activity is found to be related to the performance of various object recognition tasks. Also, bilateral and even unilateral damage to the Lateral Occipital Cortex impairs the object recognition ability and is linked to visual object agnosia (James et al., 2003; Ptak et al., 2014). Moreover, the application of transcranial magnetic stimulation to the right lateral occipital region impaired the object

recognition abilities of participants (Pitcher et al., 2009). This shows the importance of LOC in object identification and discrimination.

1.5.1 Lateral Occipital Cortex and its role in object recognition:

Since the food-object illusion videos are shown in the experiment, the Lateral Occipital Cortex is one of the regions of interest in this study. LOC has been shown to respond selectively to objects and plays an important role in object recognition (Grill-Spector et al., 2001). Not only does LOC show significant activity in the object-recognition tasks, but also its damage impairs the object recognition ability (Grill-Spector et al., 2001). Some researchers suggested that it is a multimodal object-recognition region as it responds to auditory and tactile object stimuli, as well as visual object stimuli (Palejwala et al., 2021). In an fMRI study, the LOC shows responses to Kanizsa-type illusory contours (Stanley & Rubin, 2003). Studies with infants (6 mo) also showed adult-like shape-related selective activity in the LOC (Emberson et al., 2017). In another study, transcranial magnetic stimulation application to the right Lateral Occipital region impaired the object discrimination ability of participants (Pitcher et al., 2009). These finding supports the essential role of intact lateral occipital activity for object recognition ability. More specifically, the stimuli that most of the studies include, novel objects, tools, fruits/vegetables, and everyday objects. All these stimuli are categorized under the object, so compared to other categories like faces or words, the object category includes a variety of stimuli.

1.5.2 Previous studies on how food images are represented in the brain:

Previous studies investigated neural response to food cues by presenting high-calorie food images, low-calorie food images, and non-food images in various participant groups like healthy controls or people diagnosed with an eating disorder. They aimed to understand what modulates the response to visual food cues, whether it is the

caloric content of the food images, satiety level, weight group, or eating-related behavior in general. Other than activity in the gustatory cortex and reward-related brain regions, researchers found activity in the fusiform gyrus around the fusiform face area in some studies. However, they have yet to conclude that there is food-image selectivity in the ventral visual stream. Instead, most of the studies that found activity in the fusiform in response to food images associated this significant activity with the emotional saliency of food images (Pohl et al., 2017; van Meer et al., 2015). The main goal of these researchers was generally not to understand the visual processing of the food images, but rather processing in areas beyond the visual cortex. In a meta-analysis that systematically reviews the response pattern to high-calorie food and low-calorie food viewing of healthy-weight participants, the fusiform gyrus is found to be among the concurrent brain regions that significantly get activated by high-calorie and low-calorie food images in non-food contrast (Zheng et al., 2022). The authors reported that activity in the fusiform gyrus is related to the evaluation of the calorie content, reward value of the observed food images, or the participant's hunger level. In another recent study, authors aimed to design a visual food stimuli paradigm with high-calorie, low-calorie, and non-food contrasts (Dąbkowska-Mika et al., 2023). They found significant fusiform activity in both high-calorie vs non-food contrast and low-calorie and non-food contrast. Besides other secondary association areas, they also found high fusiform activity in high-calorie vs low-calorie contrast. The authors associated this result with the fact that the fusiform gyrus is active in response to emotional picture viewing, especially for adolescents, as the food images also carry emotional value. That could also be important in explaining the result of the high-calorie vs. low-calorie contrast because high-calorie foods are found to be more pleasant, so they have more emotional value (Charbonnier et al., 2015; Zhang et al., 2023). Also, in another calorie estimation study, significant fusiform activity was observed while participants were evaluating the caloric value of foods (DiFeliceantonio et al., 2018). To evaluate the caloric value of the food image, participants need to focus on the food and recognize that. Considering the current

finding of the food-selective region in the fusiform, it is not surprising to have fusiform activity. Moreover, in another study, participants first saw visual food cues and then received tasty solutions in separate blocks of the experiment during fMRI scanning (Avery et al., 2021). The encoding results revealed that the fusiform gyrus discriminates between the food picture categories, whether the picture belongs to sour, sweet, or salty food. The authors associated their results with the higher-order processing of food pictures, like making decisions on the caloric content or category. Even though the previous attempts and meta-analyses show the activity to food images in the fusiform, the conclusions show variance between them. Some attributed the involvement of the fusiform to the processing of appetite, evaluating the reward value of foods, or decision-making based on the caloric value of the food (Zheng et al., 2022). Thus, the fusiform gyrus activity in response to food images needs further investigation to determine the more exact spatial location and selective activation pattern relative to other category-selective regions in the fusiform.

As explained in the previous paragraphs, the category-selective regions play a significant role in the recognition of the selective category. The previous associations of food-image activity in the fusiform are related to the higher-order cognitive processes that are related to foods, but still need further investigation. Viewing food could evoke different cognitive processes as the image involves information about its' healthiness, calorie value, possible ingredients, reward value of the food, and palatability, and reward activity could vary by person depending on the hunger level, body mass index, and personal preferences about foods. Thus, what the ventral food stream represents and how it relates to food choices and other food-related behaviors needs further investigation. Thus, the current study aims to investigate the whole brain activity in response to viewing illusion-like objects and cake videos called 'hyper-realistic cake videos.'

1.6 Illusion-like hyper-realistic cake videos as stimuli:

Visual illusions have been used as stimuli in visual perception studies for years. Illusions enable scientists to investigate the cognitive processes underlying perception. It is also an important tool for understanding the underlying neural mechanisms, as the mismatch between the stimuli and the perceived characteristics could inform about the neural processing of the visual information (Gori et al., 2016). Visual illusions are also studied in clinical populations, such as dyslexia, autism spectrum disorder, or schizophrenia (Notredame et al., 2014). Illusions are also used to study category selectivity in the ventral stream. For instance, Rubin's face-vase illusion is used as a stimulus for investigating the face selectivity in the visual cortex (Hasson et al., 2001; Wang et al., 2017). Relevant to this paper's research aim, they found significant FFA activity during the face perception condition while participants viewed the face-vase illusion, not vase perception. In both conditions, the low-level features of the stimulus were constant. Thus, the activity of the FFA is a result of face perception. Another reason that we employ the illusion-like videos is that these videos are fun and engaging even without performing any task. People enjoy watching these hyper-realistic cake videos, as these videos have great viewing statistics on social media platforms. During functional neuroimaging experiments, participants are presented with the same stimuli over several repetitions. It is important to keep their attention stable over the runs, so employing engaging and surprising videos would keep their attention on the videos and make them enjoy the experiment.

In this current research, we aim to employ a novel object-food illusion task to investigate the neural activity to visual food cues. To this end, we use hyper-realistic cake videos as an object-cake illusion. Hyper-realistic cake videos begin with a view of an object, and throughout the video, the hand with a knife appears and slices the object, and a layered cake appears inside the object in the beginning. Thus, the observer of the video first perceives the object, and after the knife cuts the object, the

observer realizes that the object is made of cake. We can define the hyper-realistic cake videos as illusion videos because the initial perception of the viewed object as an inedible non-food object switches to the perception of cake. Thus, the perception of non-food objects becomes illusory, as the viewed objects are food objects from the beginning. Thus, similar to the face-vase illusion, these videos create object–food illusions through the video. The flow of the hyper-realistic cake videos and control intact object videos, and how these videos are created, is explained in the Methods section.

1.6.1 Hypothesis-driven investigation of the food selectivity

Studies that revealed the visual food selectivity in the ventral visual cortex are data-driven studies, either with specific hypotheses or exploratory ones (Contier et al., 2024; Jain et al., 2023; Khosla et al., 2022; Pennock et al., 2023). Among these studies, new data were collected to investigate food selectivity in the fusiform gyrus in one study (Jain et al., 2023). Also, other aforementioned studies that employed food images as a stimulus and found fusiform activity have not formed hypotheses on food-image responses in the visual cortex. They primarily investigated how neural responses vary among varying calorie content, hunger level, or eating behaviors in the gustatory cortex or the whole brain. Thus, hypothesis-driven studies and investigating the ventral food selectivity with a new set of data are important in terms of replicating the recent findings with different data. Also, instead of using static food images, we aim to apply dynamic object-food illusion videos. Video-driven brain activity yield consistent brain responses across a large portion of the cortex (Byrge et al., 2022). Since we live in a dynamic environment, investigating object recognition with dynamic video stimuli can increase the responsiveness of brain responses. The comparison of the brain responses to moving and static stimuli in category-selective brain regions showed that the lateral selective areas respond to moving stimuli more than the static ones. However, ventral regions like FFA and EBA showed no

significant difference in responses to moving and static stimuli (Pitcher et al., 2009). How the fusiform food region activity would differ between video and image stimuli is open to investigation. Since we aim to apply the food localizer with images and the food-object illusion videos, we will be able to capture the differential brain response, if any.

1.7 The aim of the current study:

In the current study, we aim to investigate the neural response to visual food cues by using hyper-realistic cake videos in the human brain. We chose hyper-realistic cakes as a medium for investigating the visual food cue selectivity for several reasons. Firstly, these videos provide valuable tools to investigate the relative location of object-selective brain regions and food-selective brain areas as the visual perception of the viewer switches between regular objects and food perception. Thus, we can investigate the spatial location of the ventral food stream relative to the lateral occipital cortex, which is an important region in object recognition (Emberson et al., 2017; Grill-Spector et al., 2001; Ptak et al., 2014). Another important reason is that they are engaging and attention-grabbing, as reflected in the views and share statistics of these videos on social media, and also have a reality show about hyper-realistic cakes on Netflix. It is important to maintain participants' attention throughout the experiment, especially in neuroimaging studies. Since these videos are engaging, it would be easier to sustain participants' attention in the MR. The third reason is that using videos as experimental stimuli in fMRI research is not as prevalent as using images, but videos also provide an important source of investigation in neuroscience (Byrge et al., 2022). To investigate the brain regions responsive to visual food cues, we conducted two studies in this project. Although hyper-realistic cake videos as visual stimuli provide a novel method with several aforementioned benefits, we need behavioral confirmation that these videos are realistic enough to be believable. That's why we conducted a behavioral task validation study before neuroimaging. In

Experiment 1, we aimed to validate the experimental videos to be used in Experiment 2. During the behavioral study, participants are presented with the hyper-realistic cake videos, and they are asked to indicate whether the object in the video is cuttable with a blunt knife or not (cuttability). Their responses to this question should reflect their beliefs about how realistic these hyper-realistic cakes are as inedible non-food objects. We aimed to confirm differences in perception and behavioral ratings in response to hyper-realistic cake videos compared to the control videos.

Hypothesis 1.1: Hyper-realistic cake videos will be processed longer than control videos as they are surprising, so the response times for hyper-realistic cake videos are longer than control videos.

Hypothesis 1.2: Participants will have a greater surprise level when they expect the object to be uncuttable.

In addition to the hypotheses listed above, we had several aims to conduct Study 1:

Aim 1.1: Collecting ratings of disgust, edibility, and wanting from hyper-realistic cake videos. The videos that yield disgust and outliers in other variables are removed from the stimulus set.

Aim 1.2: Determining the average time of the perceptual from-object-to-cake switch during hyper-realistic cake videos. That information is useful for fMRI analysis.

Aim 1.3: Collecting the surprise ratings after the first presentation of hyper-realistic cake videos, to confirm participants are surprised by the objects transforming into a cake.

After determining the final stimulus set according to the results from Experiment 1, we conducted Experiment 2. The first aim of Experiment 2 is to localize the face-selective, object-selective, and food-image-selective brain regions in the ventral

visual cortex. The second purpose of Experiment 2 is to measure the brain activation patterns in response to the validated video stimuli with fMRI. Here are the hypotheses for Experiment 2:

Hypothesis 2.1: We hypothesize to observe an increase in the FFA activity in response to adult face images in the functional localizer task.

Hypothesis 2.2: We hypothesize to observe an increase in the LOC activity in response to object images in the functional localizer task.

Hypothesis 2.3: We hypothesize to observe an increase in the Ventral Food Stream activity in response to food images in the functional localizer task.

Aim 2.1: Determining the category-selective brain regions in each subject.

Hypothesis 2.4: We hypothesize that we will observe increased activity in the fusiform cortex by whole-brain analysis after the objects in the videos are cut and revealed to be a cake while participants are watching hyper-realistic cake videos relative to the intact object videos and before the knife cut in the cake videos.

Aim 2.2: Investigating the significant brain activity in response to hyper-realistic cake videos and control object videos in the whole brain.

Aim 2.3: Investigating the agreement between the localizer task results and hyper-realistic cake video results in terms of activated brain regions.

CHAPTER 2

METHODS

2.1 EXPERIMENT 1 – Behavioral validation of the task that will be used in the fMRI

2.1.1 Participants

We recruited 22 healthy participants (mean age=21.24 $\pm$ 1.33; age range: 18-24; 12 female) from Bilkent University students. They were given 10 points for the GE250 course credits upon their participation. They all had normal or corrected-to-normal vision. The study procedure (both Experiment 1 and 2) was approved by the Human Research Ethics Board of Bilkent University. Participants were informed about the procedure before the experiment, and they signed the informed consent form. The experiment was conducted in the Bilkent University Psychology laboratories.

2.1.2 Stimuli

Hyper-realistic Cake Videos:

Before going into the details of the experiments conducted in the current study, it would be better to explain the hyper-realistic cake videos that are used as experimental visual stimuli in both of the experiments explained below. Hyper-realistic cake videos are illusion-like and widespread on social media platforms, as they are interesting and attention-grabbing. This type of video showcases the expertise of cake artists and usually depicts a realistic-looking object that is actually made of cake on the inside. The videos generally start with an object shown either in isolation or in its context,

then a knife approaches the object and slices into the object with unexpected ease to reveal a layered cake that is often colorful and appetizing. Thus, it becomes evident that the non-food object in the video is actually an edible cake. To make these objects look realistic, the pastry chefs use additional skills from the figurative arts, such as sculpting and painting. This requires a lot of expertise, and also a fun challenge for pastry chefs, such that there are competitions of these cake artists as reality shows on Netflix *Is It Cake?* - Netflix. These videos form illusion-like experiences for the observer because the observer first perceives the object as a non-food object, then they find out their perception is wrong; it is a cake that looks like an object. These videos are widespread; there are even videos mocking the hyper-realistic cakes because they look so real that people get shocked and even disappointed. We used the hyper-realistic cake videos as experimental stimuli in our study. We used hyper-realistic cake videos of 22 objects, like a wallet, a book, and a mouse (see Figure 2). The videos and cakes were created by a cake artist who is well-known and regarded as one of the best in the hyper-realistic cake business around the world.

Object Videos:

As control videos, we used the versions of the videos where the knife approached the object but can not slice into the object. We refer to these as “intact object videos”. The intact object videos start the exact same as the hyper-realistic cake videos until the knife touches the object. After the knife touches the object, the knife tries to cut it by going back and forth on the surface of the object. After attempts to cut, the knife disappears from the screen, and the object remains intact. Thus, we used two types of videos in the study: hyper-realistic cake videos (HRC) and intact object videos (IO). Since we manipulated the preexisting hyper-realistic cake videos digitally and created uncuttable, intact object versions of them, everything in the videos is identical. The only difference between videos is that, in the hyper-realistic cake version, the object transforms into a cake. Except for this, the colors, knife, hand, and the movement are

constant in both hyper-realistic cake and intact object versions of the same object identity.

Video Creation:

We bought the usage rights of several videos from a very popular cake artist based in Turkiye -Red Rose Cake-. After we obtained the videos, we edited them to have controlled backgrounds, length, and frames. In each video, the knife touches the object in the same frame (frame 13), and each video lasts 4 seconds and has 126 frames. We removed the backgrounds using SAM2 by segmenting the objects, knives, and hands in the videos from all other background objects, and after that, we added grey background. Thus, in the end, we have the object, the knife, and the hand are visible in the videos with a gray background. To create the object videos (control videos), we digitally edited hyper-realistic cake videos for which we had acquired the usage rights. First, we identified the frame where the knife makes contact with the object surface. We then aligned this contact frame to always occur at the 13th frame across all videos. In order to simulate the visual impression of a failed cutting attempt, we reversed the timeline of the video from the frame where the knife moved across the object without cutting it, back to frame 13. Between these two time points, we implemented a boomerang-like effect by repeatedly alternating the playback direction between forward and backward. After the final backward playback, we rewound the entire video back to the beginning. As a result, each object video starts with a static image of the object. Then, through the boomerang effect, the knife repeatedly moves toward and away from the object surface without cutting it. Finally, the knife retreats in the direction it came from, without ever making a successful cut. Thus, as a result, we had 22 hyper-realistic cake videos and 22 uncuttable intact object videos, with constant length and background.

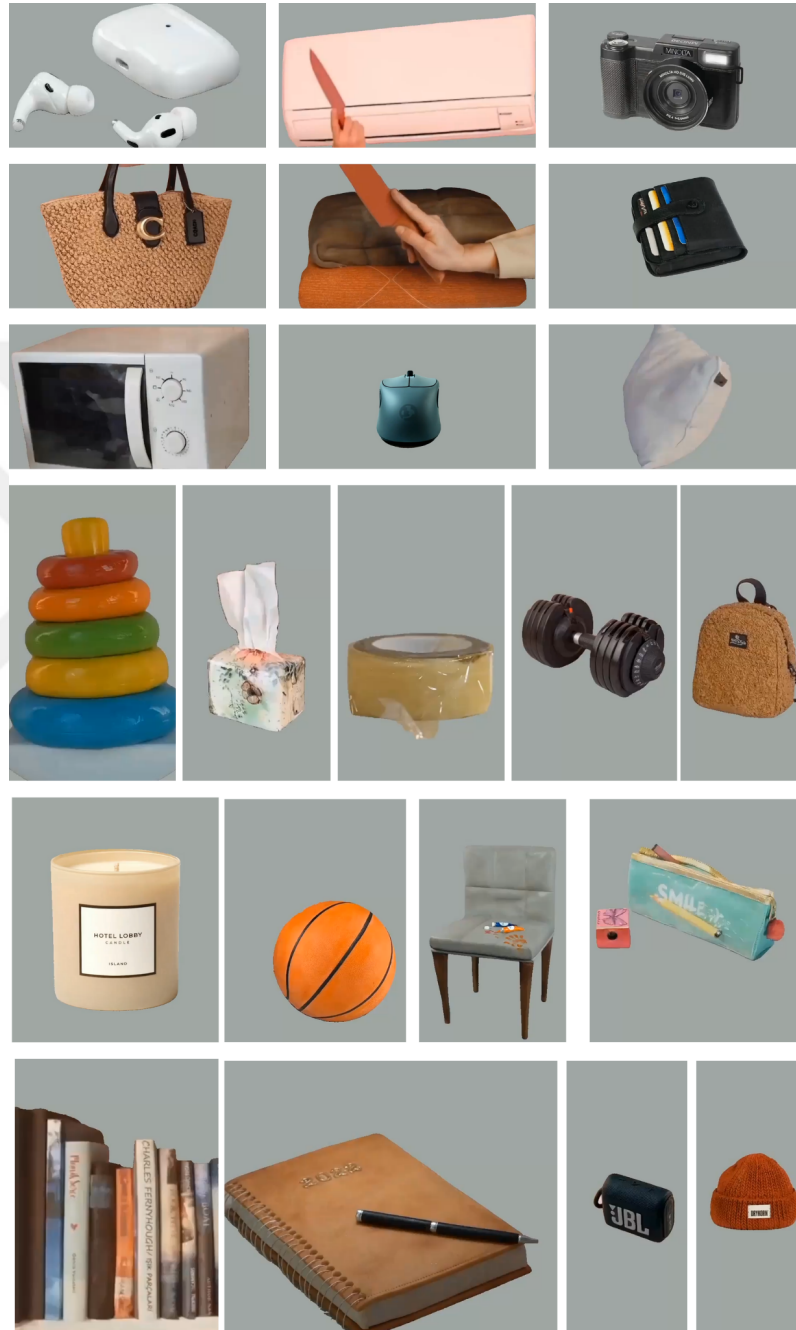


Figure 2: The images of objects used in the experiment. This figure shows the first frame of the object videos. From left to right: AirPods, air conditioner, camera, bag, blanket, wallet, microwave, mouse, pillow, toy, tissue box, tape, dumbbell, backpack, candle, basketball, chair, pencil case, bookshelf, notebook, jbl, and hat.

A. Frames from hyper-realistic cake videos



B. Frames from control videos

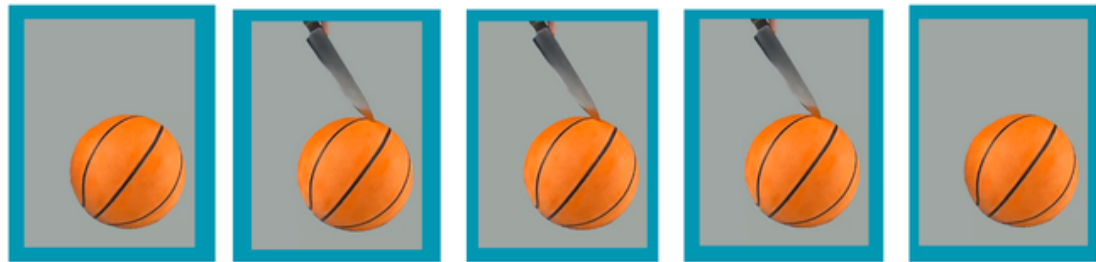


Figure 3: Frames from Videos. A) Example frames from hyper-realistic cake videos. The video starts with the still intact object, and on frame 13 the knife touches to the object and the knife slices the object, and the cake reveals. B) Example frames from control-object- videos. The video starts with the still intact object, and on frame 13 the knife touches to the object, knife goes back and forth on the surface of the object and can't cut the object.

2.1.3 Experimental Design

Although hyper-realistic cake videos are potentially suitable experimental materials to investigate the ventral food stream, we need behavioral validation that people perceive both the intact object viewed as a non-food object and the later cake after the knife. Also, we aim to measure the time of the perceptual switch from object to cake, which will be useful while analyzing the fMRI data. We also collected surprise ratings, only after the first hyper-realistic cake video presentation of each object identity. If participants think the object is uncuttable and has higher surprise ratings, the object-cake illusion works. However, if they had low surprise ratings, the cakes that looked like non-food objects were not realistic enough for those participants. Another important aim of the behavioral task is to collect various ratings about several perceptual attributes like disgust, wanting, and edibility to have a better-controlled stimulus set for the neuroimaging part. Some objects could yield a disgust response from participants or create discomfort because of the change in form from being an object to a cake. Thus, the outlier object identities in these attributes will be removed from the actual stimulus set. The behavioral experiment consists of two consecutive sessions: the training and the experimental session.

Training session:

The training session involves participants passively watching the non-cuttable intact object videos repeatedly in a random order. Twenty-two different object videos are presented 5 times during the training session. The aim of the training session is to generate a prior expectation that the videos that participants will watch during the experiment are all non-cuttable, intact object videos. Because these hyper-realistic cake videos are widespread on social media, participants may already believe the object is actually made of a cake after seeing that there is a knife coming on the screen toward the object. If so, we may fail to see the hypothesized neural activity increase after the knife cuts the object in the fMRI experiment. Considering that

expectations can change perception in case of ambiguous stimuli, participants' perception of objects might be influenced by these expectations (de Lange et al., 2018). We aim to form a valid expectation that the objects that are presented during the experiment are actual objects, even though the knife appears. Thus, by showing only the non-cuttable object videos in the training part, we aim to decrease their potential prior to hyper-realistic cake videos and re-establish the appropriate prior expectation that they are videos of objects that are normally not cuttable. In a material perception study conducted by Malik et al., the authors used similar methods in terms of having a training block to create new priors about novel objects, and they concluded that, by training, participants built new context-specific priors (Malik et al., 2023). Relying on their findings, we aim for participants to create an expectation that the objects they watch are intact, even though there is an attempt to cut them. We refer the reader to Figure 4, where they can see the flow of the training session. At the end of the training session, we aim to understand whether the training session worked. Thus, participants are shown pictures of objects that they have watched the uncut videos of. Participants are then asked the cuttability question, which is "Do you think this object could be cut through with a dull knife?" A 'Yes' response of participants would indicate that the participant did not fall into the object-cake illusion either because the cakes are not realistic as an object, or the participant might have experience with those hyper-realistic cake videos. They might follow the Instagram account of the person who owns the videos, or they might watch the Netflix show regularly, so this makes them more critical of the hyper-realistic cakes. A 'No' response of the participants indicates they perceived the objects as realistic.

Experimental session:

The second session of the behavioral experiment is the experimental session, in which participants are shown both cuttable and non-cuttable versions of the videos and asked to answer several questions during the session. The experimental session

consists of three different blocks; the first block involves participants watching of each object 60% of non-cuttable intact object versions and 40% of the cuttable hyper-realistic cake versions in a randomized order. Thus, participants were shown each object two times in the cuttable hyper-realistic cake version and three times in the intact object version. We refer the reader to Figure 4, where they can see different blocks and the flow of the experimental session. A single trial starts with a question, and the video starts after the question disappears from the screen. The question is, ‘Based on the interaction between the knife and the object that you have watched in the previous session, do you think the object in the video can be cut with a dull knife?’ They are asked to respond as soon as possible after they decide to understand when the perceptual shift happens from object to cake. If their perception changes, it is important to reveal when it happens. In a recent EEG study, the authors investigated the temporal dynamics of food representation in the human brain (Moerel et al., 2024). They found that the human brain can discriminate food images from non-food images around 112 ms after the image presentation. This result reveals that food discrimination occurs really quickly in the brain. We aim to measure the time course of the perceptual shift from object to cake in the experimental videos. After the first cake videos of each object identity, participants are asked to rate their surprise level from 0 to 100. It is important to mention that the knife touched the cake in the same frame number (frame 13) for all videos to have a reliable time for the perceptual switch. After the first block, participants were shown each video once more, and they rated several attributes like edibility, wanting, and disgust levels of the objects or cakes they watched in the video.

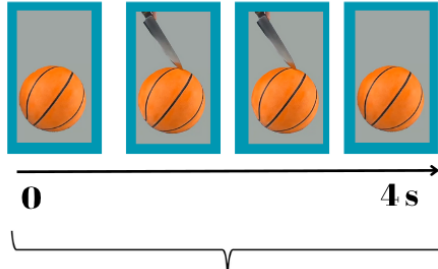
2.1.4 Presentation of the videos

We created the experiment with PsychoPy software (Peirce et al., 2019). The experiment is presented on the LCD monitor with a refresh rate of 60 Hz and a 1920 x

A. Training Session

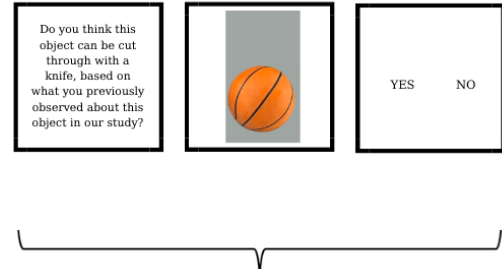
A.1 Video block

100% uncuttable control videos



22 different objects, each
repeated 5 times
110 videos in total

A.2 Question block



22 different objects, only an image of the object was shown

B. Experimental Session

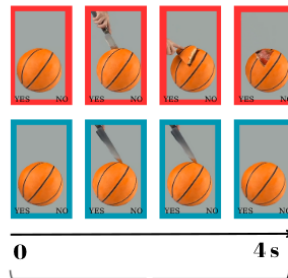
B.1 Practice block



B.2 Video block

hyperrealistic cake videos 40%

uncuttable object videos 60%



22 different objects
2 X hyper realistic cake
3 X uncuttable object
110 videos in total

B.3 Rating block

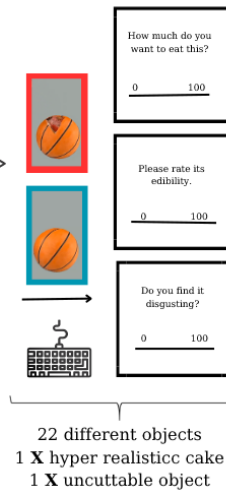


Figure 4: The overview of Experiment 1. A) Training session includes a video block and a question block. Participants watch only the uncuttable object videos during the training. B) Experimental session consists of practice block, video block, and ratings block.

1080 resolution. We collected the data in the silent experiment room, and participants were seated around 50 cm away from the monitor.

2.1.5 Data Analysis

The dependent variables of Study 1 are as follows: ‘cuttability’ - the participants’ responses to the cuttability question (Do you think this object is cuttable with a blunt knife?)-, ‘response time’ - the participants’ response times to the cuttability question during video presentation-, ‘correctness’ -the correctness of the cuttability responses, so correct responses are when participants respond ‘Yes’ to hyper realistic cake videos and ‘No’ to intact object videos-, ‘rating responses’ - participants’ responses to surprise, wanting, edibility and disgust ratings.

We used R (R Core Team, 2023) to clean and organize the data into more meaningful data frames and used JASP (JASP Team, 2025) to perform statistical analyses. For the training session, the proportion of ‘Yes’ and ‘No’ responses to the cuttability question at the end was evaluated by object type and by participants separately. That shows the better object videos in terms of how realistic they are, as well as the variability among the participants’ perceptions about the cuttability of objects. Due to the greater percentage of ‘Yes’ for the cuttability question, four participants and four object identities were removed from further analysis. These four participants respond to the majority of objects as cuttable. They might understand that these objects are made of cakes upon seeing the knife and the objects together, if they encounter hyper-realistic cake videos on social media frequently. Also, they might have unrealistic expectations about object properties, such that objects that are made of tough materials, like an air conditioner and a dumbbell, are cuttable with a knife. In addition to the participants, we removed 4 objects from our stimulus set as they are perceived as cuttable by the majority of participants, so these videos are not suitable for use in the current experiment. These objects are a chair, a bag, a bookshelf, and a ball. Thus,

the remaining analyses are conducted with 18 participants and 18 object identities.

For the experimental session, we first conducted response time analysis for the first presentation of the cake and object videos of each object type. The aim is to investigate the difference in response time by video type (2 levels: intact object and cake) to observe the effect of surprise on response time. To this end, we conducted a linear mixed model; response time for the first presentations as a dependent variable, video type as a fixed effects variable, and participants as a random effects grouping factor. Secondly, we investigated the response time difference between video types in repeated trials. Since participants watched the intact object and cake videos in the fMRI repeatedly, the difference in response time for cake and object videos is informative about modeling BOLD responses. In case there is a difference in response time for intact object and cake videos, we need to use different onset times depending on the video type while specifying the fMRI model. To this end, we conducted a linear mixed model; response time as a dependent variable, video type (2 levels), object type (18 levels), and correctness (2 levels) as fixed effects variables, and participants as a random effects grouping factor. Also, to investigate the participants' surprise level after seeing each object type as cuttable in the hyper-realistic cake videos for the first time, we conducted a one-sample t-test, and compared the surprise ratings with the test value of 50, which is the middle value in the scale. Moreover, to investigate how the surprise ratings are affected by participants' responses to the cuttability question, we conducted a linear mixed model. Surprise rating responses as a dependent variable, cuttability responses as a fixed effect, and participants as a random effect grouping factor. For the ratings, a separate two-way ANOVA for each rating, which are edibility, wanting, and disgust, was applied. For each ANOVA, the rating responses are dependent variables, and video type (2 levels) and object identity (18 levels) are fixed factors.

2.2 EXPERIMENT 2 – fMRI Task

2.2.1 Participants

15 healthy participants (mean age: 26.2, age range: 20-55, 11 female) within the normal-weight BMI range (18.5–24.9) were recruited from mostly Bilkent University students and several outside of the Bilkent community. Participants are reimbursed with 600 Turkish Liras upon completing all three sessions. All participants have normal or corrected-to-normal vision with MR-compatible glasses. Participants are informed about the requirements for entering the MR room and asked to dress in MR-compatible clothing before the experiment day. They are scanned with a metal detector before the experiment, and the MR experiment participation form is signed. Participants are informed about the procedures of the experiment and sign the informed consent form, and they are debriefed after the last session of the experiment.

2.2.2 Stimuli

The same video stimuli were used as in Experiment 1.

2.2.3 Experimental Design

The second experiment consists of 4 sessions on three different days. The first session is a training session that is the same as the training session in Experiment 1. Since we collected data from different participants than Experiment 1, we needed to train participants on uncuttable object videos. According to the cuttability responses of the participants in the training session, we proceed or do not proceed to the MR sessions of the experiment. We will continue only with participants who report at least 14 objects as uncuttable among 18 objects. The reason for excluding other participants is that, after the behavioral study, we realised that some participants think most objects are cuttable even though they were trained during the training session, so they do not

create the appropriate prior for the experiment. Thus, we decided to get participants' expectations about the cuttability of objects first, then continue with the participants who perceive the objects as uncuttable intact objects. The second session is the functional localizer task session. The third session is the main experiment session in which participants are shown the hyper-realistic cake videos. The last session was the rating session, in which participants rated both their internal states and several attributes of videos. The test days are completed within a week to reduce the possible effect of memory or other confounding factors such as history and maturation.

Training session:

This session is exactly the same as the behavioral training session, except the training session is conducted in the behavioral research laboratory on a separate day. Right after the training session, we calculated the percentage of 'Yes' and 'No' responses of each participant. We continue with the participants who responded uncuttable to a minimum of 14 objects among 18. We excluded 3 participants after the training session.

Food image localizer session:

A functional localizer task that consisted of grayscale images of foods, objects, faces, and scrambled images was employed. The aim of the localizer session is to generate spatial maps for the ventral food region, lateral occipital cortex, and fusiform face area to assess overlap with the activity evoked by videos.

We had five different categories in the localizer task (food images, object images, adult face images, scrambled images, and baseline). The scrambled images are created by phase-scrambling all images in the stimulus set. Before scrambling, all images were equalized using the SHINE toolbox to control for low-level properties such as luminance and contrast. The scrambled images are randomly selected from

the scrambled folder. Thus, the phase-scrambled images were created from the images in the stimulus set from all categories. We refer the reader to the original paper by Stigliani et al., where they can find more information about the functional localizer task and the GitHub page of the functional localizer task (Stigliani et al., 2015).

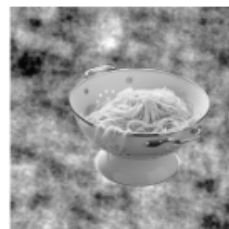
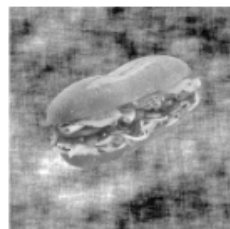
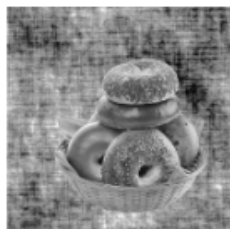
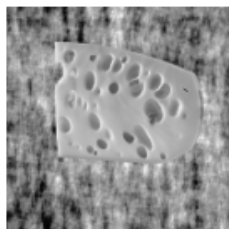
In the previous finding on the fusiform food selectivity, the authors located the fusiform food region relative to the fusiform face area (Jain et al., 2023; Khosla et al., 2022; Pennock et al., 2023). They concluded the Ventral Food Stream as medial and lateral to the Fusiform Face Area. Thus, a fusiform face area localizer is included to investigate the location of the ventral food stream relative to FFA. To locate the VFS, the ' $food > (baseline + face + object + scrambled)$ ' contrast was created. In the rest of the thesis this contrast is written as 'Food vs Others'. Similarly, for LOC, the ' $object > (baseline + face + food + scrambled)$ ' contrast was created (Object vs Others). To localize the FFA a ' $face > (baseline + food + object + scrambled)$ ' contrast was generated (Face vs Others). A localizer task that has been used largely in the domain-selectivity literature was utilized, and that localizer task consists of grayscale images of several object categories (Stigliani et al., 2015). Thus, a pre-existing localizer task that had been used and validated by previous studies was employed in the Study. In Figure 5, the example images from each category are shown. Participants are presented with 80 grayscale images from each category: food, object, face, and scrambled. To maintain participants' attention on the images, they performed a one-back task. In the one-back task, participants are asked to press a button when the current image is the same as the previous one. Participants with a performance lower than 80% correct didn't continue the experiment. Since the task is not challenging and all participants performed above the threshold, we did not exclude any participants. Jain et al. concluded that there is no difference when they collected the functional localizer data with 4 runs and 9 runs (Jain et al., 2023). Thus, we collected the localizer task in 4 runs, and each run lasts for 5 minutes and 28 seconds, and we gave breaks between runs upon participants' requests (around 25

min. in total). The stimuli are presented on the MR-safe LCD monitor (TELEMED PMEco, Istanbul, Turkey; 32-inch LCD display; 60 Hz refresh rate; 1280x768 pixels). The monitor is placed near the rear end of the scanner bore, and viewed by the participants from a distance of 165 cm via a mirror mounted on the head coil. The dependent variable in the functional localizer session is the BOLD responses, and the independent variables are different categories (food, object, face, scrambled).

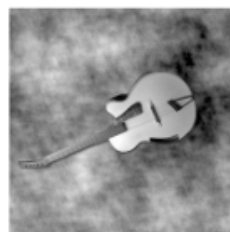
Main fMRI video session:

The main fMRI video session involves participants passively watching hyper-realistic cake and intact object videos without an explicit task. Participants are presented with 40% cuttable cake videos and 60% uncuttable object videos for each object identity. Since we want participants to continue to believe that all videos are object videos before they see the inside, a greater percentage of the videos are intact object videos. Each participant is presented with a unique random order of the videos with jittered interstimulus intervals between 3 and 5 seconds. Also, to be able to fit an hemodynamic response function (HRF) to the before and after the cut, the videos are frozen randomly between 1 and 4 seconds in the 13th frame, which is the frame when a knife touches the object. Participants are presented with 16 different object identities. The objects are divided into two groups to decrease the duration of a single run. In each run, participants are presented with the videos of 8 objects. Each video lasted, including the random freezing duration, on average, 8 s (125 frames), cake videos were repeated 2 times, and object videos were repeated 3 times in a single run. Each run lasts around 7 minutes. Each participant completed six runs, so the functional runs lasted 45 minutes on average, with some breaks in between runs upon the request of participants. The flow of the hyperrealistic cake videos and the object videos is explained above and represented in Figure 3. Participants are presented with the videos with the same set-up as the functional localizer session, and the same EPI sequences are applied during scanning. The video session involves two independent

Food



Object



Face



Scrambled

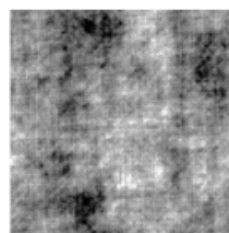
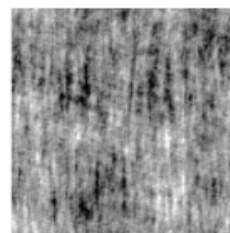
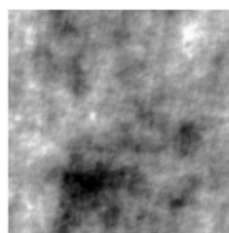
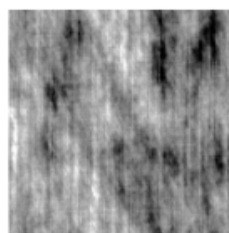


Figure 5: Localizer task. Example images presented during the localizer task.

variables: the video type (2 levels: cake and object) and the object identity (16 levels: a full list of objects can be found in the supplementary table). The dependent variables in the main fMRI task is the BOLD response.

2.2.4 Data Acquisition

MR images are collected on a 3 Tesla MRI scanner (Magnetom Trio, Siemens AG, Erlangen, Germany) with a 32-channel array head coil at the National Magnetic Resonance Research Center (UMRAM), at Bilkent University. Participants gave responses using an MR-compatible button box (Current Designs, Philadelphia, USA). Before the stimulus presentation and functional runs, we applied a localizer, structural scan, and field map. Structural images are collected with a T1-weighted MPRAGE (TR = 2600 ms; TE = 2.92 ms; flip angle = 12°; acceleration factor = 2; 176 sagittal slices with a resolution of 1 x 1 x 1 mm³). Functional images are acquired with a T2*-T2-weighted gradient-recalled echo-planar imaging (EPI) sequence (TR: 2000 ms; TE: 22 ms; flip angle: 90°; spatial resolution: 2.5x2.5x2.5 mm³; number of slices: 44; slice orientation: parallel to calcarine sulcus).

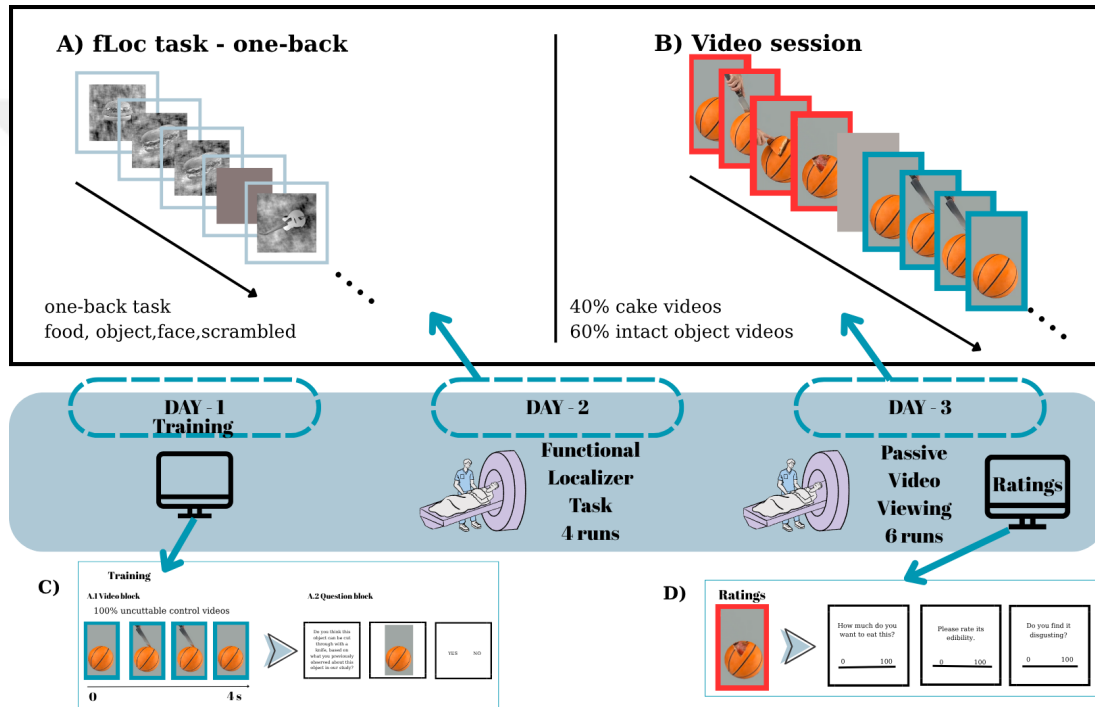


Figure 6: The overview of Experiment 2. On Day 1, participants completed the training session, and they watched the uncuttable object videos repeatedly. (C) At the end of the training session, they are asked to answer the cuttability question for each object type. We calculated the number of 'yes' and 'no' responses to the cuttability question. Participants who reported at least 14 objects as uncuttable continue with the other two sessions. (A) On Day 2, participants completed a functional localizer task during fMRI scanning. They execute a one-back task while presented with a series of images. (B) On Day 3, they watched object-food illusion videos during fMRI scanning. (D) At the end of the MR, they completed the rating session.

2.2.5 Preprocessing

The fMRI preprocessing is performed by SPM12 (*SPM - Statistical Parametric Mapping*, 2011). First, DICOM files were converted to NIFTI file format by using the `dicom2nii` function of MRICroGL in BIDS format. To anonymize the participants, defacing of high-resolution structural images was applied. After acquiring NIFTI files, Realignment (Estimate & Reslice), Slice Timing Correction, Coregistration, Segmentation, Normalization, and finally Smoothing preprocessing steps were applied in order. In the realignment step, the functional images are realigned to the mean of the functional images. Then the realigned functional images were coregistered to each participant's own anatomical image in the coregistration step. The slice timing acquisition differences were corrected. We applied segmentation to the coregistered anatomical image to separate tissue types. In the normalization step, we normalized the functional images to the MNI template image. Then, functional images are smoothed with a 6 mm FWHM Gaussian smoothing kernel.

2.2.6 Data Analysis

Functional Localizer Session - First Level Analysis:

After preprocessing, we conducted univariate analysis using the SPM12 tool. The Artifact Detection Tools (ART) toolbox for MATLAB was used to detect global mean and motion outliers in the functional data. Motion parameters were included as regressors in the design matrix at the single-subject level. In addition, image volumes in which the z-normalized global brain activity exceeded 3 SDs from the mean of the run or showed 1 mm of composite (linear plus rotational) movement were flagged as outliers and deweighted during SPM estimation. We applied high-pass filtering at a 128-second cutoff to remove noise signals from the data. We specified the fMRI model by using the general linear model (GLM). We had five conditions: food, object, face, scrambled, and baseline. We generated the design matrix by matching

the onset and duration of each condition from event files to model the event-related responses by the hemodynamic response function (HRF) in SPM12. The GLM is applied to estimate the condition-specific effects in each voxel. After the model estimation, we specified the contrast maps to test the condition-specific effects for each participant separately. We created several contrasts, and some of them are: Food > Object, Food > Face, Food > Baseline, Food > Scrambled, Food > Others, Face > Others, and Object > Others. The contrasts for the food selective, face selective, and object selective regions were created by referring to the original fLOC paper by Stigliani et al. for the category-selective regions in the fusiform (Stigliani et al., 2015). To define the functional regions of interest in their study, they created contrasts of 'faces > others' and 'bodies > others', to localize the face-selective region and the body-selective region relatively.

Functional Localizer Session - Second Level Analysis:

In the second-level analysis, we aimed to investigate group-level brain responses by aggregating the results from individual-level contrasts. To this end, a one-sample t-test was performed on each contrast of interest to identify the common activation pattern across participants. Anatomical labels for the significant brain regions are manually labeled using human brain atlases. We used a small volume correction (sphere with 10 mm radius, containing 47 voxels) defined from a region of fusiform that responds to food images (at coordinate [left: -30 -56 -10, right: 38, -74, -14]) (van der Laan et al., 2011). The t-map threshold was set at p uncorrected < 0.01 and a cluster size of at least 5 contiguous voxels. Clusters were considered significant at P < 0.05, Family Wise Error (FWE) corrected across the whole brain or a small volume search.

Video Session - First Level Analysis:

Following preprocessing, the univariate analysis was conducted by SPM12. The ART

toolbox for MATLAB was used to detect global mean and motion outliers in the functional data, as explained in the first-level analysis paragraph above. Motion parameters were included as regressors in the design matrix at the single-subject level. In addition, image volumes in which the z-normalized global brain activity exceeded 3 SDs from the mean of the run or showed 1 mm of composite (linear plus rotational) movement were flagged as outliers and deweighted during SPM estimation. We applied high-pass filtering at a 128-second cutoff to remove the noise signals from the data. The GLM is used for model specification. In the video session, there are four conditions: cake video before knife, cake video after knife, object video before knife, and object video after knife. The design matrix was created by matching the onset and duration of the cake and object videos from event files to model the event-related responses by hemodynamic response function (HRF) in SPM12. Since the cake videos start with the object view and the cake appears in the 13th frame of the cake videos, we created the design matrix by subtracting the onset of the 13th frame from the onset of the cake videos. The GLM is applied to estimate the single-trial condition-specific effects in each voxel. After the model estimation, the contrast maps were specified to test the condition-specific effects for each participant separately. The BOLD responses were compared by several contrasts: 'Cake After Knife > Cake Before Knife', 'Cake After Knife > Object After Knife', and '(Cake After Knife – Cake Before Knife) – (Object After Knife – Object Before Knife)' contrasts. The 'Cake After Knife > Cake Before Knife' should isolate the neural activity to an object being a food. The only difference between Cake After Knife and Cake Before Knife conditions is that the intact object transforms into a food after the knife cuts. 'Cake After Knife > Object After Knife' contrast should also isolate neural activity to Food, but that contrast is equated for time passed, looking at an intact object before the knife approaches. However, we may get additional processes that we are not interested in. For instance, the "After Knife" period for intact objects may evoke continued searching for the reveal of a cake or a disappointment that no cake was revealed. When we look at the double contrast, '(Cake After Knife – Cake

Before Knife) – (Object After Knife – Object Before Knife)', we are not only equating time passed before the cut, but we are also subtracting out those processes related to expectation that we are not primarily interested in. The activity in the predefined regions was compared after analysing the functional localizer for each participant. A GLM analysis was applied to the fMRI time-series data to estimate single-trial beta responses.

Video Session - Second Level Analysis:

In the second-level analysis, we aimed to investigate group-level brain responses by aggregating the results from individual-level contrasts from the fMRI video session. Thus, a one-sample t-test was performed on each contrast defined above to identify the common activation pattern across participants. Anatomical labels for the significant brain regions are manually labeled using human brain atlases. We used a small volume correction (sphere with 10 mm radius, containing 74 voxels) defined from a region of fusiform that responds to food images (at coordinate [left: -30 -56 -10, right: 38, -74, -14]) (van der Laan et al., 2011). The t-map threshold was set at p uncorrected < 0.005 and a cluster size of at least 5 contiguous voxels. Clusters were considered significant at $P < 0.05$, Family Wise Error (FWE) corrected across the whole brain or a small volume search.

CHAPTER 3

RESULTS

3.1 EXPERIMENT 1 RESULTS: - Behavioral validation of the task

3.1.1 The end of the training block responses

To investigate whether the passive viewing of the uncuttable object videos repeatedly before the experimental block reached its aim, which is creating a prior belief that these videos belong to actual objects, we asked participants' ideas about the cuttability of each object type by asking 'Do you think this object is cuttable with a blunt knife?'. Since hyper-realistic cake videos are widespread on social media, there is a possibility that participants have prior beliefs that regular objects can also be cakes, already. To this end, we investigated the participants' answers to the cuttability question at the end of the training session. We examined the proportion of yes/no responses by participant. Also, we examined the proportion of yes/no responses by object type, in case a specific object type is responded to as more cuttable than others. Thus, we conducted binomial tests to measure the total counts of yes and no responses to the cuttability question.

Table 1: Binomial Test

Variable	Level	Counts	Total	Proportion	p	95% CI for Proportion	
						Lower	Upper
air conditioner	No	16	18	0.889	< .001	0.690	1.000
	Yes	2	18	0.111	1.000	0.020	1.000
candle	No	16	18	0.889	< .001	0.690	1.000
	Yes	2	18	0.111	1.000	0.020	1.000
blanket	No	15	18	0.833	0.004	0.623	1.000
	Yes	3	18	0.167	0.999	0.047	1.000
tissuebox	No	12	18	0.667	0.119	0.446	1.000
	Yes	6	18	0.333	0.952	0.156	1.000
mouse	No	18	18	1.000	< .001	0.847	1.000
toy	No	15	18	0.833	0.004	0.623	1.000
	Yes	3	18	0.167	0.999	0.047	1.000
wallet	No	15	18	0.833	0.004	0.623	1.000
	Yes	3	18	0.167	0.999	0.047	1.000
airpods	No	17	18	0.944	< .001	0.762	1.000
	Yes	1	18	0.056	1.000	0.003	1.000
tape	No	13	18	0.722	0.048	0.502	1.000
	Yes	5	18	0.278	0.985	0.116	1.000
pillow	No	16	18	0.889	< .001	0.690	1.000
	Yes	2	18	0.111	1.000	0.020	1.000
hat	No	16	18	0.889	< .001	0.690	1.000
	Yes	2	18	0.111	1.000	0.020	1.000
camera	No	17	18	0.944	< .001	0.762	1.000
	Yes	1	18	0.056	1.000	0.003	1.000
jbl	No	17	18	0.944	< .001	0.762	1.000
	Yes	1	18	0.056	1.000	0.003	1.000
notebook	No	14	18	0.778	0.015	0.561	1.000
	Yes	4	18	0.222	0.996	0.080	1.000
pencilcase	No	13	18	0.722	0.048	0.502	1.000
	Yes	5	18	0.278	0.985	0.116	1.000
dumbell	No	18	18	1.000	< .001	0.847	1.000
microwave	No	14	18	0.778	0.015	0.561	1.000
	Yes	4	18	0.222	0.996	0.080	1.000
backpack	No	14	18	0.778	0.015	0.561	1.000
	Yes	4	18	0.222	0.996	0.080	1.000

Table 3.1 shows the one-tailed binomial test results. Apart from the tissuebox, all other object types are significantly judged as ‘not cuttable’ more than chance level (0.5). The least cuttable object types are mouse and dumbbell, as not a single participant regarded those as cuttable ($p < .001$). Also, the highest proportion of ‘Yes’ responses to the ‘Do you think this object cuttable with a blunt knife?’ question among these object types were given to the tape and the pencil case ($p < .05$). We excluded some objects, such as chair, ball, bag and bookshelf, because of the greater percentage of ‘Yes’ responses to the cuttability question were given to those objects, which means participants mostly perceive those objects as cuttable. Apart from those, we excluded tape and microwave from our stimulus set to have a higher-quality stimulus set. As a result, we proceed with 16 object types for the fMRI experiment.

Table 2: Binomial Test

Variable	Level	Counts	Total	Proportion	p	95% CI for Proportion	
						Lower	Upper
ss-01	No	14	18	0.778	0.015	0.561	1.000
	Yes	4	18	0.222	0.996	0.080	1.000
ss-02	No	18	18	1.000	< .001	0.847	1.000
ss-03	No	10	18	0.556	0.407	0.341	1.000
	Yes	8	18	0.444	0.760	0.244	1.000
ss-04	No	16	18	0.889	< .001	0.690	1.000
	Yes	2	18	0.111	1.000	0.020	1.000
ss-05	No	17	18	0.944	< .001	0.762	1.000
	Yes	1	18	0.056	1.000	0.003	1.000
ss-06	No	15	18	0.833	0.004	0.623	1.000
	Yes	3	18	0.167	0.999	0.047	1.000
ss-07	No	18	18	1.000	< .001	0.847	1.000
ss-08	No	18	18	1.000	< .001	0.847	1.000
ss-09	No	13	18	0.722	0.048	0.502	1.000
	Yes	5	18	0.278	0.985	0.116	1.000
ss-10	No	11	18	0.611	0.240	0.392	1.000
	Yes	7	18	0.389	0.881	0.199	1.000
ss-11	No	18	18	1.000	< .001	0.847	1.000
ss-12	No	12	18	0.667	0.119	0.446	1.000
	Yes	6	18	0.333	0.952	0.156	1.000
ss-13	No	15	18	0.833	0.004	0.623	1.000
	Yes	3	18	0.167	0.999	0.047	1.000
ss-14	No	16	18	0.889	< .001	0.690	1.000
	Yes	2	18	0.111	1.000	0.020	1.000
ss-15	No	17	18	0.944	< .001	0.762	1.000
	Yes	1	18	0.056	1.000	0.003	1.000
ss-16	No	18	18	1.000	< .001	0.847	1.000
ss-17	No	18	18	1.000	< .001	0.847	1.000
ss-18	No	12	18	0.667	0.119	0.446	1.000
	Yes	6	18	0.333	0.952	0.156	1.000

The result table (Table 3.2) shows the proportion of Yes and No responses to the cuttability question by each participant, to capture the potential perceptual difference between participants. One-tailed binomial test results show whether each participant is significantly more likely to judge objects as not cuttable than would be expected by chance level (0.5). The majority of participants (12 out of 18) perceived the objects as 'not cuttable' more than chance level ($p < 0.05$).

3.1.2 Response time analysis

RT analysis of the first presentations:

In the experimental block, participants saw each video two times as a cuttable hyper-realistic cake video and three times as an uncuttable object video for each object type. They are asked the same cutability question during video presentations, and they gave responses while watching the videos. To understand the effect of surprise on response time, we investigated the response time difference between video types for the first presentation of each object type. The response time here refers to the duration from the start of the video until participants respond to the question 'Is this object cuttable with a blunt knife?' during the video presentation. To this end, we conducted a linear mixed model; response time as a dependent variable, video type as a fixed effects variable and participant as a random effects grouping variable. As a result of the linear mixed models, we observed no significant difference on response time between video types ($F = 2.33, p > .05$).

Table 3: Linear Mixed Models - Response Time

Effect	df	F	p
video type	1, 23.32	2.333	0.140

RT analysis of all trials:

To investigate how the response time for the cuttability question is affected by object type (18 levels), video type (2 levels: cake and intact object), and the correctness (2 levels: correct and incorrect) of the responses, we conducted a linear mixed model with participants as a random effects grouping factor, video type, object type, and correctness as fixed effects variables, and video response time as a dependent variable. Since participants are presented with intact objects and cake videos repeatedly in the fMRI experiment, we wanted to understand whether there is a difference in response time among video types. In case there is a significant difference between intact object and cake videos, we need to use different onsets while modeling BOLD responses. The linear mixed model results revealed that the video type has no significant effect on response time ($F=0.46, p=.51$). This means that, while conducting fMRI analysis, we can model the BOLD response event onsets with the same delay for both video types. We also observed a significant effect of object type ($F=4.28, p<.001$) and correctness ($F=13.95, p<.05$) on response time.

Table 4: Linear Mixed Models - Response Time

Effect	df	F	p
video type	1, 12.40	0.461	0.510
object type	17, 35.15	4.275	< .001
correctness	1, 15.61	13.945	0.002

3.1.3 Surprise Ratings Analysis

We collected surprise ratings only after the first view of the cake videos for each object type. Thus, we have surprise ratings only for the cake videos. We want to test whether participants have greater surprise levels compared to the middle value on the scale. As a result of the one-sample t-test, there is a significant difference between the test value (50) and the surprise ratings ($p < .001$). Also, we want to assess whether participants are more surprised when an object turns into cake when participants are expecting no cake (cuttability question is answered with “no”), relative to when they

expected it would be a cake (cuttability question is answered with “yes”). Thus, we conducted a linear mixed model with participant as a random effects factor and cuttability as a fixed effects variable and surprise ratings as the dependent variable. This analysis showed a significant effect of cuttability expectation on surprise ratings ($F(1,14.64) = 23.786$, $p < .001$), such that participants are more surprised when the object turns into a cake ($M = 73.97$, $SE = 3.27$) when they expect an object relative to when they expected no cake ($M = 40.75$, $SE = 6.20$).

Table 5: One Sample T-Test - Surprise Ratings

	t	df	p
surprise rating	5.679	282	< .001

Table 6: Linear Mixed Models - Surprise Ratings

Effect	df	F	p
cuttability expectation	1, 14.64	23.786	< .001

3.1.4 Ratings Analysis - Edibility, Wanting, Disgust

In this section, the edibility, wanting, and disgust rating results will be presented. These rating responses are important to understand participants’ perceptions about the object types and the videos presented throughout the experiment.

We conducted a two-way ANOVA to investigate the effect of object type and video type on edibility judgments. There is a significant effect of object type ($F(17, 612) = 1.661$, $p = .046$), so some objects are found to be more edible than others. Also, as expected, the video type has a substantial effect on the edibility judgements ($F(1, 612) = 409.692$, $p < .001$). The participants rated the cake videos ($M = 70.67$, $SD = 29.57$) as more edible than the object videos ($M = 24.13$, $SD = 29.24$).

The two-way ANOVA results for the wanting ratings revealed that both object type ($F(17, 612) = 2.033$, $p = .008$) and the video type ($F(1, 612) = 182.779$, $p < .001$)

have a significant main effect on wanting to eat ratings. Similar to edibility results, video type has a greater effect size than the object type. The cake videos ($M = 48.22$, $SD = 33.78$) yielded a greater desire to eat the presented stimuli compared to object videos ($M = 18.08$, $SD = 22.5$).

The last rating collected is disgust ratings, which is important to understand participants' perceptions of the object-cake transformation. A high level of disgust would lead to differential brain responses for some specific object types, so it is important to be aware of the participants' disgust judgements. The two-way ANOVA results suggested no significant effect of object type ($F(17,612) = 0.244$, $p = .999$) and video type ($F(1, 612) = 3.779$, $p = .052$) on disgust level. Also, the mean of the disgust ratings is 29.33 ($SD = 31.57$, $Min = 1$, $Max = 100$). Thus, we don't need to remove any object type from our stimulus set to be used in the fMRI.

3.2 EXPERIMENT 2 RESULTS: fMRI Task

3.2.1 Functional Localizer Task Results

In the functional localizer task session, we presented adult face images, object images (cars and instruments), food images, and scrambled images. Thus, we can localize the face-selective FFA, object-selective LOC, and food image-selective ventral food streams by creating the face vs others, object vs others, and food vs others contrasts relatively.

Neural Responses to Food Images in the Fusiform Gyrus:

To locate the ventral food stream in each participant, we created several contrasts. In **Figure 8**, you can see the 'Food vs others' contrast in each participant. Since the previous studies on the food image selectivity in the fusiform concluded that the location of ventral food regions shows more variation across participants compared to

other category-selective regions (Jain et al., 2023), we want to show the food-selective regions separately in each participant. The first-level analysis for 'Food vs Others' revealed voxels with significant activity to Food images compared to other categories in the fusiform for each participant (See Figure 7). Despite the variation in the location of the Food activity, we observed significant clusters in the fusiform. We conducted a one-sample t-test of the contrast of 'Food vs Others' from the first-level analysis at $p < .01$. We identified significant clusters that are more responsive to food images than other categories near the recently discovered ventral food stream. The predominant coordinates are shown in the result table in the Appendices (Table A.3). We also created contrasts like 'Food vs Face', 'Food vs Object', 'Food vs Scrambled', and 'Food vs Baseline'. You can see the second-level analysis results for those contrasts in the **Figure 9** at $p < .01$. Also, for demonstration, you can see the coordinates for the current cluster with significant activity in Figure 8 for each contrast. The food-responsive coordinates are in agreement with the coordinates that show greater activity to visual food cues identified by a meta-analysis (van der Laan et al., 2011). Unlike other contrasts, no significant cluster was left after the 'Food vs Object' contrast at $p < .01$. The potential reasons is discussed in the discussion section.

Neural Responses to Object Images in the Lateral Occipital Cortex:

The second important region in the current study is the object image selective Lateral Occipital Cortex. To localize the object-selective brain region, we conducted a one-sample t-test of contrast of Object - (Baseline + Face + Food + Scrambled) from the first-level analysis. You can see the significant clusters after second-level analysis, at FWE uncorrected $p < .01$ significance threshold (see Figure 9). The MNI coordinates for LOC are documented as $x = 40, y = -70, z = -8$ for right, and $x = -38, y = -78, z = -6$ for left hemisphere (Karten et al., 2013).

Neural Responses to Face Images in the Fusiform Face Area:

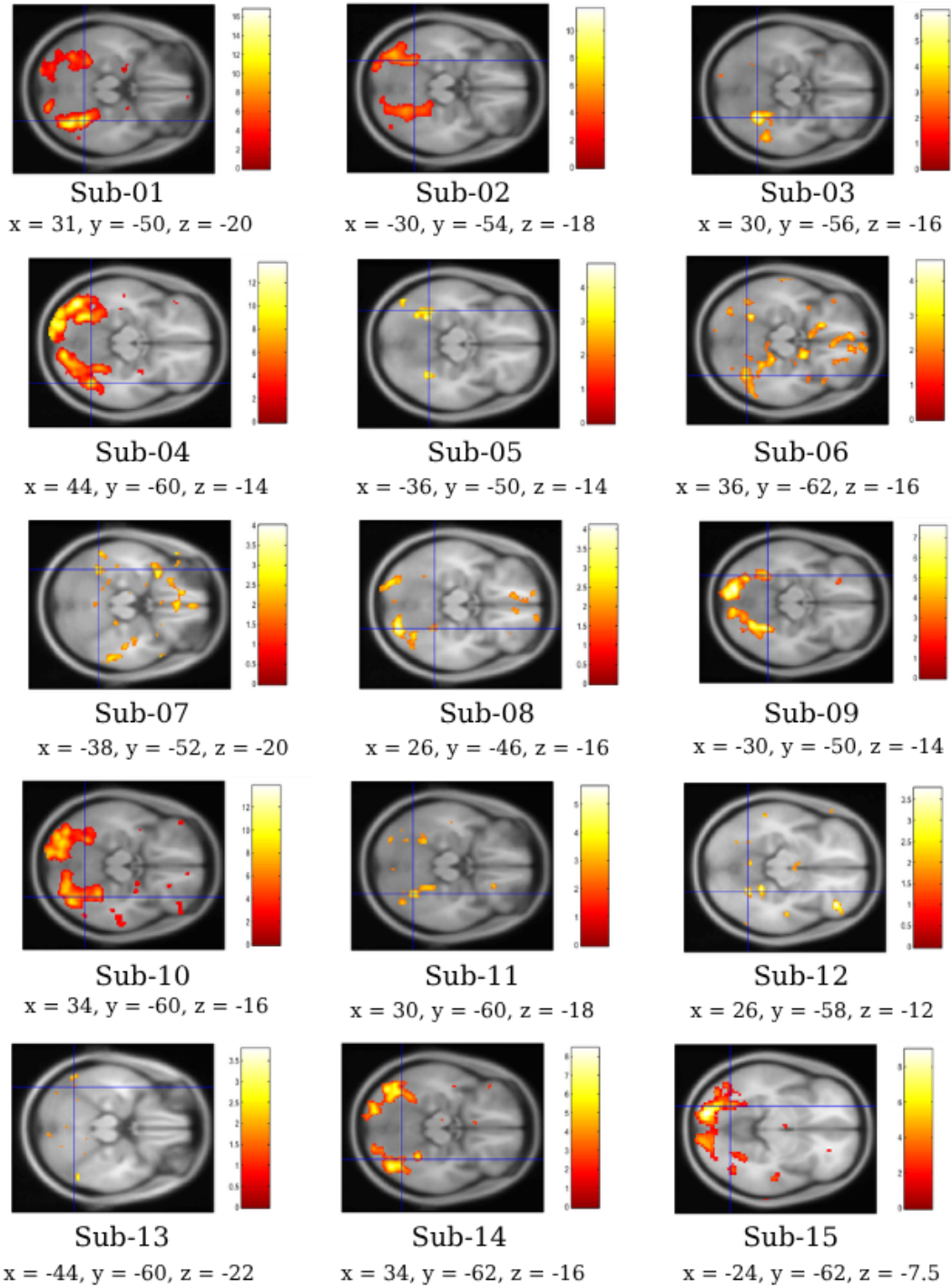


Figure 7: Food vs Others contrast. This figure shows "Food vs Others" contrasts results for each participant ($p < .01$). The color gradient of the clusters depicts t values. Height threshold $T = 2.33$

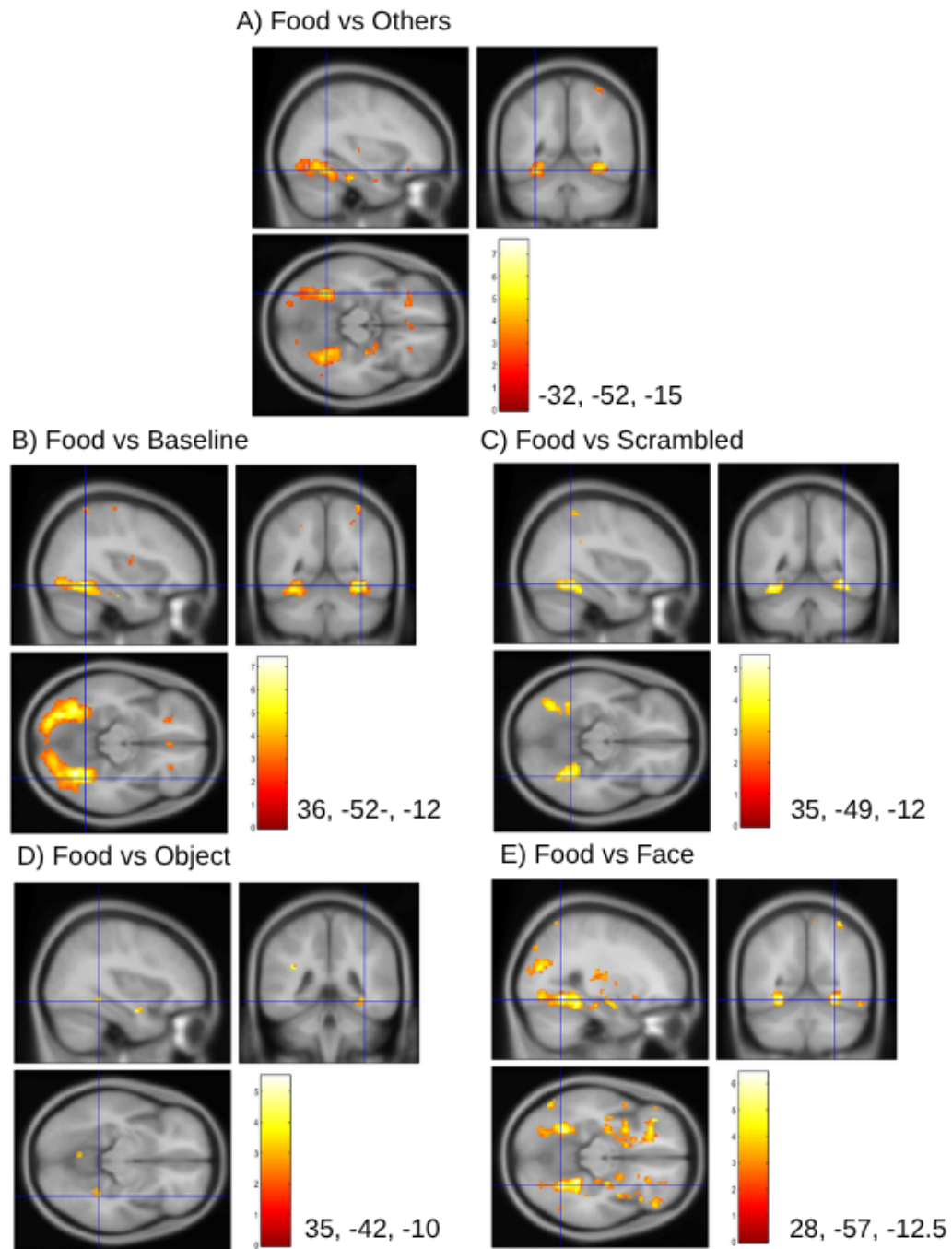


Figure 8: Group Level Neural Response to Food Contrasts ($p < .01$). The color gradient of the clusters depicts t values. Height threshold $T = 2.62$

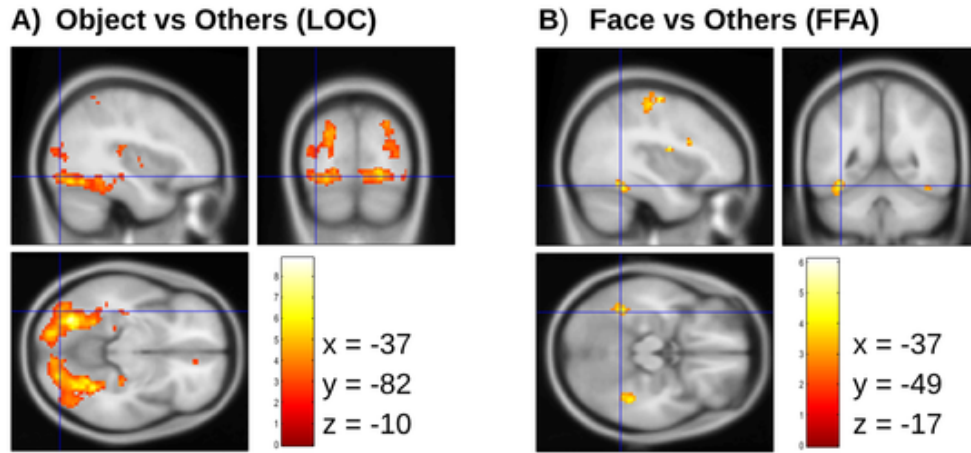


Figure 9: Group Level Neural Responses to Object and Face Images. The color gradient of the clusters depicts t values. Height threshold $T = 2.62$

In the localizer task, we presented images of adult faces to localize the face-selective Fusiform Face Area. In the studies on food image selectivity in the fusiform, the authors described the food image selective areas relative to the FFA (Adamson & Troiani, 2018; Khosla et al., 2022; Jain et al., 2023). Thus, we wanted to localize FFA to compare our results with the initial findings on food selectivity. We conducted a one-sample t-test of the contrast of 'Face vs Others' from the first-level analysis. Despite showing variation across studies, the Talairach coordinates for the FFA are documented as $x = 40$, $y = -55$, $z = -10$ for right, and $x = -35$, $y = -63$, $z = -10$ for left hemisphere (Kanwisher et al., 1997). The MNI counterpart of the FFA coordinates are nearly $x = 41$, $y = -54$, $z = -18$ for right, and $x = -36$, $y = -63$, $z = -107$ for left hemisphere. This conversion is done by the MNI to Talairach converter tool: BioImage Suite. Taking into consideration that these regions show variation among people, we can conclude that in both face and object selective regions, our results are consistent with the previous literature.

3.2.2 Video Session Results

In the main fMRI Video session, participants passively watched hyper-realistic cake videos and control object videos in a random order. We randomized the order of the videos, inter-stimulus intervals, and freeze duration of videos uniquely per participant to control for any possible confounding order effect and the time effect. We divided each video into two parts: before and after the knife. Thus, in total, we have Cake Before Knife, Cake After Knife, Object Before Knife, and Object After Knife conditions. To compare the brain activity, especially in the fusiform food region, after the knife cuts the object into a cake, we generated the following contrasts and conducted a one-sample t-test. The contrasts are; 'Cake After Knife > Cake Before Knife', 'Cake After Knife > Object After Knife', and '(Cake After Knife – Cake Before Knife) – (Object After Knife – Object Before Knife)'. These three contrasts show the clusters that show greater activity in response to the Cake videos after the knife cut. In the other three conditions, the participant's perception should be of an intact object. Thus, the 'Cake After Knife' condition reveals the 'Food' selective brain responses. Moreover, to confirm that the activity from the 'Cake After Knife > Cake Before Knife' belongs to only Cakes, we created another contrast for object videos: 'Object After Knife > Object Before Knife'. This contrast enables us to compare the significant activity resulting from the Cake After Knife vs Cake Before Knife contrast is special to the viewing of a Cake.

As it can be seen from the Figure 10, the 'Cake After Knife vs Cake Before Knife' contrast revealed a significant brain response at $p < .005$, around the fusiform cortex in both right ($x = 33, y = -47, z = 10$) and left hemispheres ($x = -34.5, y = -57, z = -7.5$). After the object is cut by a knife and the video reveals that the object is actually a cake, several clusters in the ventral visual stream showed significantly greater brain response. This result aligns well with our hypothesis that the food image selective regions in the fusiform will show increased activity when the participants become

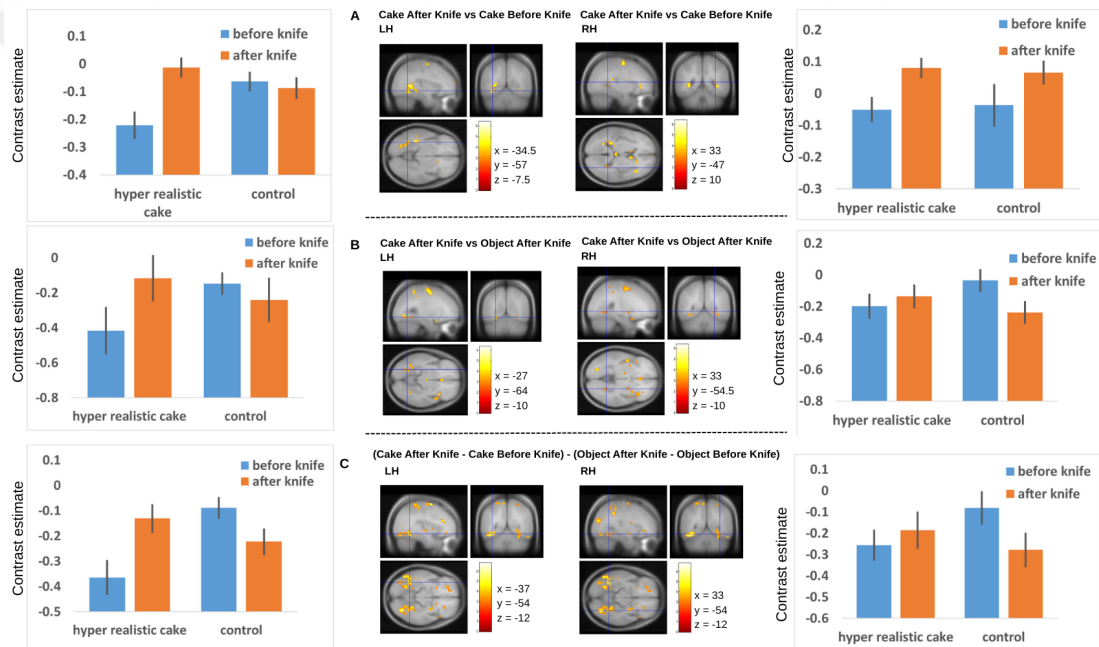


Figure 10: Group Level Neural Response to Video Contrasts ($p < .01$). The y axis on the bar graphs show contrast estimates in arbitrary units. The orange bars represent 'After Knife' and the blue bar represents 'Before Knife'. The color gradient of the clusters depicts t values. Height threshold $T = 2.98$. A) The second-level results for the Cake After Knife > Cake Before Knife contrast. B) The second-level results for the Cake After Knife > Object After Knife contrast. C) (Cake After Knife - Cake Before Knife)-(Object After Knife - Object Before Knife) contrast.

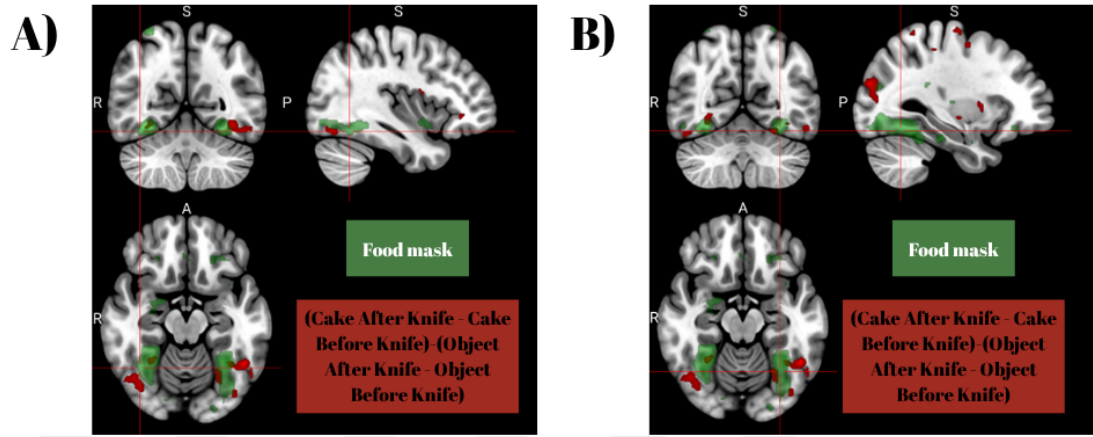


Figure 11: Food Mask and Double Contrast. This figure shows the spatial location of the food selective region (in green) at $p < .01$, and the thresholded SPM result of the (Cake After Knife – Cake Before Knife) – (Object After Knife – Object Before Knife) contrast at $p < .001$. A) Shows the peak coordinate on the right hemisphere ($x=38, y=-56, z=-14$). B) Shows the peak coordinate on the left hemisphere ($x=-30, y=-60, z=-15$).

aware that the object is actually a cake. Similarly, several clusters in the fusiform gyrus show an increased brain response in the Cake After Knife condition compared to Object After Knife at $p < .005$ ($x = 33, y = -54.5, z = -10$). We also conducted a double contrast to better differentiate the brain response to Cake After Knife from the other three conditions. To this end we conducted '(Cake After Knife – Cake Before Knife) – (Object After Knife – Object Before Knife)' contrast, and we found that there is an increased brain response to the Cake After Knife condition in the bilateral medial and lateral sides of the fusiform cortex. The most important clusters are listed in the Appendices. This finding is consistent with the initial finding for food selectivity in the fusiform (Khosla et al., 2022). Figure 11 shows the food mask, which is created after the functional localizer task. We created a thresholded SPM mask at $p < .01$ from 'Food vs All' contrast. The results from the double contrasts, (Cake After Knife – Cake Before Knife) – (Object After Knife – Object Before Knife)) at $p < .001$, were overlaid together with the food mask. There are overlapping and distinct areas for the food localizer and video task within the fusiform gyrus.

Object After Knife vs Object Before Knife

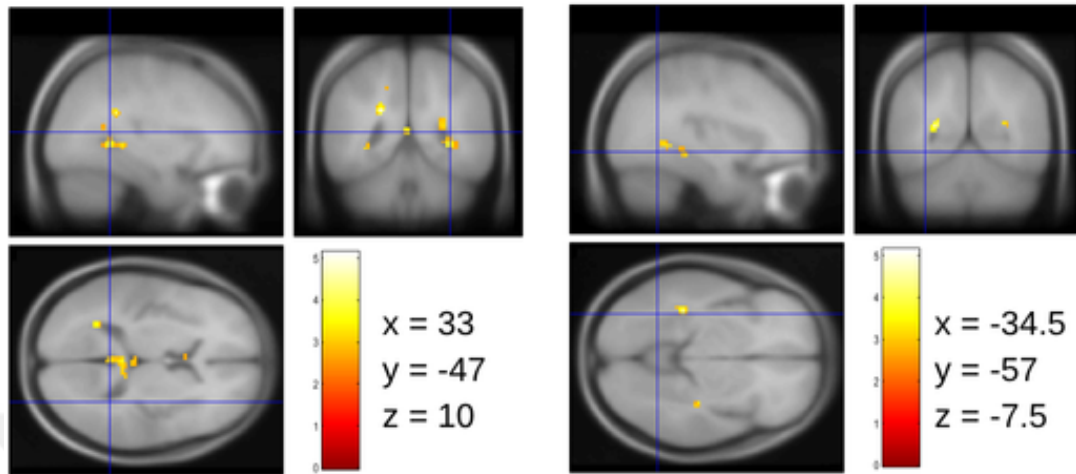


Figure 12: Object Selective Activity. This figure shows the clusters that responded more to the Object After Knife condition compared to the Object Before Knife condition. The same coordinates as Figure 10 is shown. The picture on the left shows Object After Knife > Object Before Knife contrast result at $p < .01$. Shows the peak coordinate on the left hemisphere ($x=-34.5$, $y=-57$, $z=-7.5$). The picture on the right shows Object After Knife > Object Before Knife contrast result at $p < .01$. Shows the peak coordinate on the right hemisphere ($x=33$, $y=-47$, $z=10$).

Since we want to make sure that the significant activity from Cake After Knife vs Cake Before Knife belongs to only Cake videos, we want to show the activity from Object After Knife vs Object Before Knife contrast in the voxels that is shown in Figure 10. Figure 12 shows the activity for the same coordinates as Figure 10. It is visible from the axial slices, the clusters in the same coordinate don't show significant activity in the Object Contrast. There seems to be activity in the sagittal and coronal slices in Figure 12, but they are not in the same coordinate as with the coordinates shown in Figure 10. These clusters are superior and medial to the fusiform gyrus. Also, these clusters are not significant at the voxel or peak level after correction for multiple comparisons. You can see the coordinates for clusters with peak activity in the Appendices (Table A.8).

CHAPTER 4

DISCUSSION

This study investigates selectivity for food images in the ventral visual cortex. Despite finding the consistent fusiform activity to visual food cues in several meta-analyses, 'food' is never described as a cardinal category that shows selective response in the fusiform, among other categories like faces, places, and words (van der Laan et al., 2011; van Meer et al., 2015). But, different exploratory data-driven studies from independent research groups have reported a 'food-selective' response pattern in the ventral visual stream (Khosla et al., 2022; Jain et al., 2023; Pennock et al., 2023; Contier et al., 2024). The current study investigates food selectivity in the human brain using a hypothesis-driven method by employing an object-food illusion video stimulus. Object-food illusion videos are so-called hyper-realistic cake videos, which are widespread on social media. In these videos, the non-food object perception shifts to the food perception, as through the video, the object is cut by a knife and revealed to be a cake. We conducted a behavioral experiment with 22 participants to validate the use of hyper-realistic cake videos in the fMRI experiment as an object-food illusion. We wanted to confirm that these videos are suitable for a neuroimaging experiment and whether they create the intended illusion from object to food. As a result of the behavioral study, we confirm that these videos are realistic enough as objects and create the illusion of an object. We hypothesized to find an increase in the ventral food region when the perception of the object shifts to the perception of food. For this purpose, we collected fMRI data from 15 participants. We first want to identify the food-selective region in the ventral visual cortex for each participant. To this end, we applied a functional localizer task in the first fMRI session. In the second fMRI session, participants are shown the validated object-food illusion videos, while their brain activity is being measured. As a result, we confirmed our hypothesis that

the food-selective clusters in the fusiform cortex showed increased response to hyper-realistic cake videos after the object appeared to be a cake.

4.1 Experiment – 1

In the behavioral experiment, we wanted to behaviorally validate that the hyper-realistic cake videos are effective illusions. For the illusion to be effective, the object in the video should initially be perceived as an intact non-food object. We assessed this by asking whether the participant believes that the object can be cut through easily by a dull knife (“cuttability”), after viewing multiple videos of a knife incapable of cutting the objects. We confirmed that most participants perceive most objects as non-food by giving significantly more ‘No’ responses to the cuttability question. Six objects were perceived as cuttable and were removed from the stimulus set. We removed another 2 objects that were relatively high on cuttability to decrease the duration of the fMRI session. Another aspect of an effective illusion is surprise when a cake is encountered. We assessed surprise in two ways: 1) indirectly, as reflected by longer response times; and 2) directly, as reflected by surprise ratings. For these analyses, we used only the first trials in which a specific object was revealed to be a cake, and we compared trials in which participants indicated they expected the object to be uncuttable (perceived as non-food) to those when they expected it to be cuttable. We did not observe longer response times for the first encounter with a cake when participants expected it to be uncuttable vs cuttable. As expected, we observed greater surprise ratings, confirming Hypothesis 1.2. We expected differences in response times to also reflect surprise, as processing and responding to surprising stimuli takes more time (Horstmann, 2006). However, we did not observe a difference in response times. We failed to confirm Hypothesis 1.1. The reason for this result might be due to the back-and-forth movements of the knife over the surface of the object in the control videos. To give the ‘uncuttability’ effect, we edited control videos in a way that the knife makes back-and-forth movements

over the surface of the object. Thus, it might take a participant a longer time to realize that the object in the control videos is uncuttable than the cake videos, which are directly cut by the knife. Another aspect of the illusion being effective is that intact objects should be perceived as inedible and cake objects as edible. Similarly, cake objects should score higher on “wanting to consume” ratings than intact objects. As intended, the cake objects are perceived as more edible and participants rate a higher “wanting to consume” the cake objects relative to the intact objects. We also assessed disgust ratings of the object to identify any objects that might be high in disgust, but no object needed to be removed from our stimulus set due to the disgust level. Lastly, an additional goal of the behavioral study was to compare response times to the different video types to assess whether we can use the same event onset times in the fMRI study. For this analysis we took all response times into account and observed no differences between intact object vs cake videos, which indicates that we can model the BOLD response event onset with the same delay for both Cake and Control videos for the fMRI analysis. Overall, these analyses confirm that the illusion is generally effective, because the participants see the objects initially as non-food objects and they are surprised when the cake is revealed. We conclude that these videos are valid to be used as object-food illusion videos.

4.2 Experiment — 2

Training

In the current neuroimaging experiment, we first applied training to participants to establish prior of non-food objects, and continued with the participants who had perceived at least 14 objects out of 18 as uncuttable. We recruited 18 participants to the training session for Experiment 2, and we completed data collection from 15 participants. We excluded three participants as their responses exceeded the threshold defined above.

Functional Localizer Task

In the second block of the experiment, we applied a functional localizer task. In this task, participants are presented with food, objects, faces, and scrambled images while their brain activity is measured by fMRI. To make sure that they attend to the visual stimuli during fMRI scanning, they performed a one-back task. We didn't need to exclude any participants as all participants had an accuracy level above the threshold. As a result of the group-level analysis, we confirmed our hypotheses (Hypothesis 2.1, 2.2, and 2.3), and we observed increased activity in response to preferred image presentation in the category-selective regions. We localized the face-selective FFA, object-selective LOC, and, most importantly, we observed food-image selective activity in the fusiform cortex. The coordinates in which we observed significantly greater activity in response to food images are in agreement with the previously found coordinates in meta-analysis for brain responses to food images (van der Laan et al., 2011). The recent publications about food selectivity in the fusiform do not include any information about specific coordinates. They found a selective pattern of activation to the lateral and medial sides of the FFA. Thus, we validated our 'Food' selective activity with the meta-analysis on neural correlates of visual food cues (van der Laan et al., 2011). Their activation-likelihood estimation meta-analysis identified the bilateral posterior fusiform gyrus (peak coordinates at LH: $-30, -56, -10$, at RH: $38, -74, -14$) as one of the most consistently activated clusters for visual food cues.

Our contrasts with other categories, 'Food vs Others', 'Food vs Scrambled', 'Food vs Baseline', and 'Food vs Face', showed a selective response to foods in the ventral visual stream. However, 'Food vs Object' yielded no significant activity in the fusiform. 'Food vs Others' contrast shows more responsive voxels than 'Food vs Object' contrast. One possible explanation for this result is that the object stimuli in the localizer task consist of only car and instrument pictures. That may not be enough

to capture the object category. Also, in the original paper of the localizer task by Stigliani et al., they report their findings for word-selectivity, body-selectivity, face-selectivity, and place-selectivity, but they do not report any results on the object-selective response in the LOC (Stigliani et al., 2015). Another possible explanation is that foods can be classified under the object category, as foods are edible objects. The subtraction of object-related activity from food-related activity may subtract out a major proportion of the neural representation of food objects. For other contrasts, like face or scrambled images, probably this is not the case. In a recent work, the researchers suggest that foods and graspable tools are similar in terms of the correlated actions and affordances (Ritchie et al., 2024). They investigated whether the selective response to specific categories is determined by the correlated behavior of the selective category. To this end, they compared the foods and graspable foods, and they concluded that both foods and tools elicit similar brain responses in the fusiform as they share common affordances. However, in our stimulus set, cars and instruments do not share common affordances with foods. Each of the comparisons against a single other category may suffer from different biases. For instance, food is an integral part of our lives, and consuming food is usually a social activity. People consume food while viewing others' faces, so there might be functional overlap between food and faces. Another explanation for the result in Figure 8 is, the 'Food vs Others' contrast is less sensitive to such biases, as we average across the other categories. Since the contrasts with other categories, such as Scrambled, Face, and Baseline, resulted in greater response, the averaging for the 'Food vs Others' contrast resulted in more voxels with significantly greater activity.

Figure 7 shows individual-level locations of brain regions that respond to food images in the ventral visual stream. As can be interpreted from the figure, the location of the food-image selective region shows variability across participants. This spatial variability of the neural responses across participants is also reported in the previous studies on food images (Jain et al., 2023).

Other than food-selective regions, we localized the FFA and LOC in response to face and object pictures (see Figure 9). Since the significant clusters are consistent with the FFA and LOC coordinates in previous articles and meta-analyses, we can conclude that the localizer task shows compatible results with the previous literature (Karten et al., 2013; Kanwisher et al., 1997).

Hyper-realistic Cake Videos on fMRI

In the main fMRI session of the experiment, participants watched the hyper-realistic cake and object videos while their brain activity was measured by fMRI. The 'Cake After Knife vs Cake Before Knife' contrast should isolate the neural activity to an object being a food. The only difference between Cake After Knife and Cake Before Knife conditions is the food. When we compare Cake After Knife with Object After Knife condition, we should also be isolating neural activity to food, but now we are equating for time passed, looking at an intact object before the knife approaches. However, in this contrast, we may also be looking at processes that we are not interested in. For example, the 'Object After Knife' may evoke continued searching for the reveal of a cake or a disappointment that no cake was revealed. When we look at the double contrast, we are not only equating time passed before the cut, but we are also subtracting out those processes related to expectation that we are not primarily interested in. As a result of the first contrast, Cake After Knife vs Cake Before Knife, we observed significant activity in the fusiform region. In Figure 10, you can see the significantly activated bilateral brain regions to cake observation compared to object observation during the hyper-realistic cake videos. You can see the voxel coordinates in the figure, and those coordinates match well with the meta-analysis on the coordinates of visual food cues (van der Laan et al., 2011). Thus, we can conclude that when the initial perception of the object changes to the food perception after the knife, we observed a significant increase in the food-selective brain region in the ventral visual stream. The Cake After Knife vs Object After Knife contrast also

showed significant activity in the ventral visual stream (see Figure 10). In the 3rd contrast, we generated a double contrast to better differentiate the 'Cake After Knife' evoked brain responses from the other three conditions, so we subtracted the '(Object After Knife - Object Before Knife)' from the 'Cake After Knife vs Object After Knife' contrast. As a result, as you can see in Figure 10, we observed a significant activity in the bilateral medial and lateral fusiform areas. We confirmed Hypothesis 2.4 and observed increased activity in the ventral food stream for the Cake After Knife condition. The coordinates of the significant clusters align well with the findings of recently discovered food-selective activity in the ventral visual stream (Khosla et al., 2022; Jain et al., 2023; Pennock et al., 2023). See Table A.3 for the significant clusters in the appendices. The food mask created from the functional localizer task and the contrast results from the (Cake After Knife – Cake Before Knife) – (Object After Knife – Object Before Knife)) are overlaid together in Figure 11, where overlapping and distinct regions are observed. It shows the agreement between the food localizer task and the recently developed object-food illusion video task. Also, the overlapping activity confirms that object-food illusion videos are as good as, if not better than, the functional localizer task with static images of foods. These results confirm our hypothesis. We created another contrast, Object After Knife vs Object Before Knife, to observe whether the clusters that show greater response in the Cake contrast show significant activity or not. For this purpose, we showed the clusters in the same coordinate as with the Cake After Knife vs Cake Before Knife contrast shown in Figure 10. As can be seen from Figure 12, the same clusters didn't show significant activity in Object contrasts. Clusters with peak activity from the Object After Knife vs Object Before Knife contrast is superior and medial to the significant clusters from the Cake After Knife vs Cake Before Knife contrast. This result supports our hypothesis that the significant clusters from Cake contrast in the fusiform region don't show significant activity in Object contrast, so the significant activity in the Cake contrast is observed for viewing the food, not the object. The results tables for both Cake and Object contrast are in the Appendices in Table A.6 and A.8.

4.3 General Discussion

The main purpose of the current thesis is to investigate the neural activity in response to visual food cues. However, unlike commonly used visual food cues, like high-calorie food images, low-calorie food images, processed or natural food images, we wanted to employ object-food illusion videos, so-called hyper-realistic cake videos. Hyper-realistic cake videos are widespread entertaining videos on social media platforms. In hyper-realistic cake videos, the initial non-edible object perception changes to the perception of food during the video. We wanted to apply hyper-realistic cake videos for several reasons; they serve as object-food illusion videos, they are engaging and attention-grabbing, and they enable us to create a localizer of food selective regions relative to well-documented object selective LOC. Visual illusions have been used in visual neuroscience for decades; however, to the best of our knowledge, this is the first study that investigates visual illusions in the food perception field (Hasson et al., 2001; Andrews et al., 2002; Eagleman, 2001). Also, most of the studies that investigated visual food cues generally use images of foods that are dominantly used in that culture of investigation, like Western foods (Toet et al., 2019; Sato et al., 2020; Cai et al., 2023). However, the popularity of hyper-realistic cake videos on social media makes these videos a universal tool as they do not belong to any specific culture. This contributes to the generalizability of our results.

The current thesis contributes to both the visual neuroscience and nutritional neuroscience fields. Firstly, we created an object-food illusion dataset of 16 objects. The illusion evoked surprise, and the objects switched from being perceived as inedible to edible. Unlike recent data-driven studies on food image selectivity, we conducted a hypothesis-driven study to investigate ventral food selectivity. We collected data by applying both the functional localizer task and by presenting the object-food illusion videos while measuring brain activity. In the visual perception

studies, categories like faces, houses, body parts, written texts, tools, objects, and animals are predominantly investigated and employed as visual stimuli (Kanwisher et al., 1997; Grill-Spector & Weiner, 2014; Peelen & Downing, 2017; Downing, Peelen, et al., 2006; Stigliani et al., 2015; Valdois, 2010). However, visual food cues are generally investigated in the scope of food perception and nutrition studies. For instance, the neural response to food cues is studied generally in relation to weight group, eating disorders, dietary habits, appetite, or satiety (Zheng et al., 2022; Führer et al., 2008; Santel et al., 2006; Nakamura et al., 2024). Thus, this thesis contributes to the use of food stimuli in the visual perception domain as well. Moreover, this would contribute to the food perception literature, as viewing food is the initial stage of nutrition. Before consuming any food, we first need to observe the food, evaluate its content and condition, and decide whether it is edible or not. We need to make a decision based on the initial visual observation of food. In a review article on the visual food cues, the authors argue that the visual food cues activate the core eating network, consisting of the ventral reward pathway and dorsal control pathway (Chen et al., 2016). Instead of the primary gustatory and olfactory cortices, the initial sensory input is conveyed to the fusiform gyrus for food recognition and follows a similar ventral reward and dorsal control pathway with the gustatory food cues. Thus, understanding the neural activity to food cues in the fusiform cortex, especially the food-selective ventral food stream, will increase our knowledge of the effect of visual food cues on the core eating network and eating behavior. This potential effect gained more importance during the last decade, as the food content on TV programs and the prevalence of food content on social media are substantially increasing (Philip & Bali, 2022; Filippone et al., 2022). The unfavorable effect of food content in social media on eating behavior is observed in adolescent groups (Kucharczuk et al., 2022; Patwardhan et al., 2024; Filippone et al., 2022). Thus, it is important to understand the underlying neural mechanism of visual food cues and how that relates to eating-related behavior. The results would benefit society by creating non-invasive interventions to promote healthy eating habits and also to inhibit the negative

influence of food content in social media on eating habits.

When we compare our results from the video task to the functional localizer of food images, we observe multiple differences. Which task best reflects neural responses to visual food stimuli? The food localizer is a new task that follows the design for other localizers that have been used extensively. However, results for this food localizer have been reported for 4 participants only in the literature until now. Additionally, this localizer may not be very appropriate for localizing the food area because the images are all gray-scale, and Pennock et al. showed how important color responses are in the VFS (Pennock et al., 2023). We wanted to use the food localizer to compare our results to the extremely limited existing literature, but it is important to acknowledge that the functional localizer may miss important BOLD responses related to dynamic colored images. Additionally, future studies should consider carefully how to determine the location of a control area. The LOC may not be the most appropriate choice, since foods are also objects. The face area may also not be ideal, since associations with faces and foods are strong, and neural activity to these stimuli may overlap. Future studies on functional selectivity to a wide variety of stimuli will help determine an appropriate control region of the brain and a suitable task to evoke activity in that region.

The result of this current thesis may benefit several clinical populations. Klüver-Bucy is a rare neurobehavioral disorder following the dysfunction in the medial temporal lobe (Hernández Martínez et al., 2024). Patients who are diagnosed with Klüver-Bucy syndrome show impaired object recognition, and they eat nonedible objects such as cleaning pastes, ink, and dog food (Marlowe et al., 1975). Understanding the functioning of the ventral food stream, its neural correlates with the temporal lobe in Klüver-Bucy patients, would provide important insights into the Klüver Bucy syndrome. Another disorder is food neophobia, which can be described as the reluctance to eat novel foods and showing picky eating behavior, especially in

children (Lafraire et al., 2016). However, in some cases, food-neophobia lasts until early adulthood and leads to nutrition deficiency (Nicklaus et al., 2005). It has been documented that visual information about novel fruit is more important than tactile information for children while making a decision to try the fruit (Dovey et al., 2012). Certain visual properties like color, perceived visual texture, and shape play a significant role in rejecting trying new foods (Lafraire et al., 2016). One of the reasons for rejecting trying is feeling disgusted because of the food's content (Pliner & Salvy, 2006). The current findings on food selectivity with hyper-realistic cakes would deepen our understanding of food neophobia. The neural and behavioral differences between patients and healthy controls would provide insight into the disorder and help to create interventions.

Future Directions:

The selectivity to visual food cues in the ventral visual stream is an exploratory and recent finding that is supported by the following hypothesis-driven investigations, including this thesis. The current study supports having selective responses to visual food cues in the fusiform cortex. In a recent study, researchers found stronger connectivity between the fusiform food region and the ventral tegmental area, which is an important brain region in reward-related processes, for people with a high food craving trait (Devoto et al., 2024). This finding is important in terms of understanding the potential contribution of the fusiform food region to eating-related behavior. The initial observation of food is important for us to decide whether the food is rewarding enough to eat or not. The task in the aforementioned study is a visual imagery task, so participants are not presented with any visual or food stimuli. They are asked to imagine eating the high-calorie, low-calorie foods and drinking water during a functional MR scan. Thus, future studies should investigate the connectivity of the ventral food stream with gustatory cortices, such as the insula. Understanding the nature of connectivity and how that varies between different individuals and its

behavioral relevance needs further investigation. Also, the four recent findings of food selectivity employed advanced statistical analysis methods and computational techniques, like multivariate pattern analysis (MVPA), representational similarity analysis, and modeling. Our results are based on a univariate general linear model. Thus, the current data should be analysed with more advanced techniques like MVPA. That would give more information about the pattern of brain activity in the fusiform cortex. Also, other important behavior-related dimensions have been investigated and correlated with the neural responses in the fusiform cortex (Contier et al., 2024). The current findings provide confirmation of the food-related dimension in the ventral visual stream. Further studies should investigate the important dimensions that could contribute to the Ventral Food Stream activity. For instance, how the images of different taste qualities, such as sweet and sour, and different properties like processed or natural food pictures, are represented in the Ventral Food Stream would deepen our understanding of food selectivity.

Limitations:

This current study has several limitations. Firstly, the sample size is small, due to the time constraints, we collected fMRI data from 15 participants. As a result, the analysis may be underpowered. Also, the majority of participants are female, so there might be gender-specific brain responses to food cues. Gender-specific effects are observed in fusiform activity (Frank et al., 2010). Moreover, the object images in the functional localizer task include only car and instrument images, which may not be sufficiently comprehensive to capture the object category in general. The scope of the functional localizer is important for creating contrasts for the functional localizer task. More variety in images for the object category is needed.

CHAPTER 5

CONCLUSION

In conclusion, this study investigates the neural activity to visual food cues by using hyper-realistic cake videos. In the behavioral experiment, we validated our experimental stimuli, hyper-realistic cake videos, as an object-food illusion tool in the fMRI experiment. We first applied the functional localizer task and identified the food-selective regions in the ventral visual cortex for each participant. During the main fMRI session, participants passively watched the hyper-realistic cake videos and control videos. As a result of the main video session in the fMRI, we found significantly increased brain response in the fusiform cortex during the 'Cake' perception of hyper-realistic cake videos than the 'Object' perception. This finding supports the food as a new cardinal category for the domain-selective activity in the ventral visual stream, in addition to face, place, scene, words, and body parts. Thus, this thesis confirms the food selective activity in the ventral visual stream by employing object-food illusion.

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CHAPTER A

DATA RELATIVE TO CHAPTER 3

Table A.1: Object Types

#	Object Name:
1	Air Conditioner
2	Airpods
3	Bag
4	Blanket
5	Bookshelf
6	Chair
7	Dumbbell
8	Hat
9	Microwave
10	Mouse
11	Notebook
12	Pencil case
13	Pillow
14	Tape
15	Tissuebox
16	Toy
17	Wallet
18	Ball
19	Camera
20	Candle
21	Eyeglass
22	Backpack

Table A.2: SPM Results Table: Food vs All

Cluster-level				Peak-level					
p(FWE)	p(FDR)	k	p(unc)	p(FWE)	p(FDR)	T	Z	p(unc)	x, y, z (mm)
0.000	0.000	555	0.000	0.989	0.573	5.33	3.88	0.000	28, -54, -12
				0.996	0.573	5.18	3.81	0.000	26, -44, -12
				0.997	0.573	5.12	3.78	0.000	36, -54, -12
				0.999	0.573	5.03	3.74	0.000	33, -77, -8
				1.000	0.968	4.26	3.35	0.000	30, -42, -20
				1.000	0.995	3.70	3.04	0.001	20, -84, -8
				1.000	0.995	3.55	2.95	0.002	43, -70, -8
				1.000	0.995	3.37	2.84	0.002	48, -67, -10
				0.107	0.257	7.62	4.72	0.000	-27, -77, -2
				0.999	0.573	4.97	3.71	0.000	-32, -52, -15
				1.000	0.610	4.78	3.62	0.000	-32, -62, -10
				1.000	0.759	4.55	3.51	0.000	-34, -44, -18
				1.000	0.995	3.93	3.18	0.001	-20, -90, -10
				1.000	0.995	3.74	3.06	0.001	-24, -40, -20
				1.000	0.995	3.47	2.90	0.002	-30, -44, -25
				1.000	0.995	3.05	2.62	0.004	-44, -64, -12

Height threshold: $T = 2.62$, $p = .010$ (1.000); Extent threshold: $k = 0$ voxels;
Expected voxels per cluster $\langle k \rangle = 9.323$; Expected number of clusters $\langle c \rangle = 108.39$
 $FWE_p = 8.136$; $FDR_p = \text{Inf}$; $FWE_c = 555$; $FDR_c = 555$
Degrees of freedom = [1.0, 14.0]; FWHM = 8.9 9.0 8.6 mm (space), 3.6 3.6 3.4 voxels

Volume: $1,388,734 \text{ mm}^3 = 88,879 \text{ voxels} = 1,858.8 \text{ resels}$

Voxel size: $2.5 \times 2.5 \times 2.5 \text{ mm}$ (resel = 43.66 voxels)

Table A.3: SPM Results Table: ((Cake After Knife – Cake Before Knife) – (Object After Knife – Object Before Knife))

Cluster-level				Peak-level					
p(FWE)	p(FDR)	k	p(unc)	p(FWE)	p(FDR)	T	Z	p(unc)	x, y, z (mm)
0.000	0.000	347	0.000	0.625	0.720	6.21	4.24	0.000	28, -50, -18
				0.686	0.729	6.08	4.19	0.000	36, -74, -12
				0.866	0.731	5.64	4.01	0.000	48, -62, -18
				0.896	0.731	5.54	3.97	0.000	28, -62, -5
				0.912	0.731	5.48	3.94	0.000	38, -72, -15
				0.998	0.888	4.77	3.62	0.000	26, -47, -12
				1.000	0.902	4.21	3.33	0.000	33, -54, -12
				1.000	0.908	4.03	3.23	0.001	26, -54, -2
				1.000	0.908	4.02	3.22	0.001	53, -54, -20
				1.000	0.908	4.01	3.22	0.001	23, -64, -15
				1.000	0.925	3.58	2.97	0.001	28, -64, -25
				1.000	0.925	3.44	2.88	0.002	20, -62, -22
				1.000	0.925	3.41	2.86	0.002	33, -42, -12
				1.000	0.970	3.16	2.70	0.003	38, -80, -8
				1.000	0.970	3.16	2.70	0.003	28, -82, -10
				1.000	0.972	3.15	2.69	0.004	23, -82, -8
				0.381	0.720	6.80	4.45	0.000	-47, -52, -15
				0.608	0.720	6.25	4.25	0.000	-37, -54, -12
				0.983	0.777	5.08	3.76	0.000	-52, -67, -12
				0.997	0.888	4.81	3.64	0.000	-52, -60, -12
				1.000	0.902	4.25	3.35	0.000	-40, -40, -18
				1.000	0.908	4.10	3.27	0.001	-27, -52, -8
				1.000	0.908	3.81	3.11	0.001	-22, -50, -10
				1.000	0.925	3.57	2.96	0.002	-44, -37, -20
				1.000	0.925	3.46	2.89	0.002	-44, -52, -2
				1.000	0.925	3.40	2.86	0.002	-50, -44, -12
				1.000	0.925	3.40	2.86	0.002	-47, -42, -15

Thresholds and Image Properties: *Height threshold:* $T = 2.98$, $p = .005$ (1.000); *Extent threshold:* $k = 5$ voxels, $p = .460$ (1.000)
 $\langle k \rangle = 9.714$ voxels; $\langle c \rangle = 23.72$ clusters; $FWE_p = 8.133$; $FDR_p = \text{Inf}$; $FWE_c = 134$; $FDR_c = 112$
 $df = [1.0, 14.0]$; $FWHM = 10.4 \times 10.4 \times 9.8$ mm ($4.1 \times 4.2 \times 3.9$ voxels); $\text{Volume} = 1,383,859$ $\text{mm}^3 = 88,567$ voxels = 1,194.5 resels; $\text{Voxel size} = 2.5$ mm^3 (1 resel = 67.78 voxels)

Table A.4: SPM Results Table: (Cake After Knife – Cake Before Knife)

Cluster-level				Peak-level					
p(FWE)	p(FDR)	k	p(unc)	p(FWE)	p(FDR)	T	Z	p(unc)	x, y, z (mm)
0.000	0.000	347	0.000	0.625	0.720	6.21	4.24	0.000	28, -50, -18
				0.686	0.729	6.08	4.19	0.000	36, -74, -12
				0.866	0.731	5.64	4.01	0.000	48, -62, -18
				0.896	0.731	5.54	3.97	0.000	28, -62, -5
				0.912	0.731	5.48	3.94	0.000	38, -72, -15
				0.998	0.888	4.77	3.62	0.000	26, -47, -12
				1.000	0.902	4.21	3.33	0.000	33, -54, -12
				1.000	0.908	4.03	3.23	0.001	26, -54, -2
				1.000	0.908	4.02	3.22	0.001	53, -54, -20
				1.000	0.908	4.01	3.22	0.001	23, -64, -15
				1.000	0.925	3.58	2.97	0.001	28, -64, -25
				1.000	0.925	3.44	2.88	0.002	20, -62, -22
				1.000	0.925	3.41	2.86	0.002	33, -42, -12
				1.000	0.970	3.16	2.70	0.003	38, -80, -8
				1.000	0.970	3.16	2.70	0.003	28, -82, -10
				1.000	0.972	3.15	2.69	0.004	23, -82, -8
				0.381	0.720	6.80	4.45	0.000	-47, -52, -15
				0.608	0.720	6.25	4.25	0.000	-37, -54, -12
				0.983	0.777	5.08	3.76	0.000	-52, -67, -12
				0.997	0.888	4.81	3.64	0.000	-52, -60, -12
				1.000	0.902	4.25	3.35	0.000	-40, -40, -18
				1.000	0.908	4.10	3.27	0.001	-27, -52, -8
				1.000	0.908	3.81	3.11	0.001	-22, -50, -10
				1.000	0.925	3.57	2.96	0.002	-44, -37, -20
				1.000	0.925	3.46	2.89	0.002	-44, -52, -2
				1.000	0.925	3.40	2.86	0.002	-50, -44, -12
				1.000	0.925	3.40	2.86	0.002	-47, -42, -15

Thresholds and Image Properties: Height threshold: $T = 2.98$, $p = .005$ (1.000); Extent threshold: $k = 5$ voxels, $p = .460$ (1.000)

$\langle k \rangle = 9.714$ voxels; $\langle c \rangle = 23.72$ clusters; $FWE_p = 8.133$; $FDR_p = \text{Inf}$; $FWE_c = 134$; $FDR_c = 112$

$df = [1.0, 14.0]$; $FWHM = 10.4 \times 10.4 \times 9.8$ mm ($4.1 \times 4.2 \times 3.9$ voxels); Volume = 1,383,859 $\text{mm}^3 = 88,567$ voxels = 1,194.5 resels; Voxel size = 2.5 mm^3 (1 resel = 67.78 voxels)

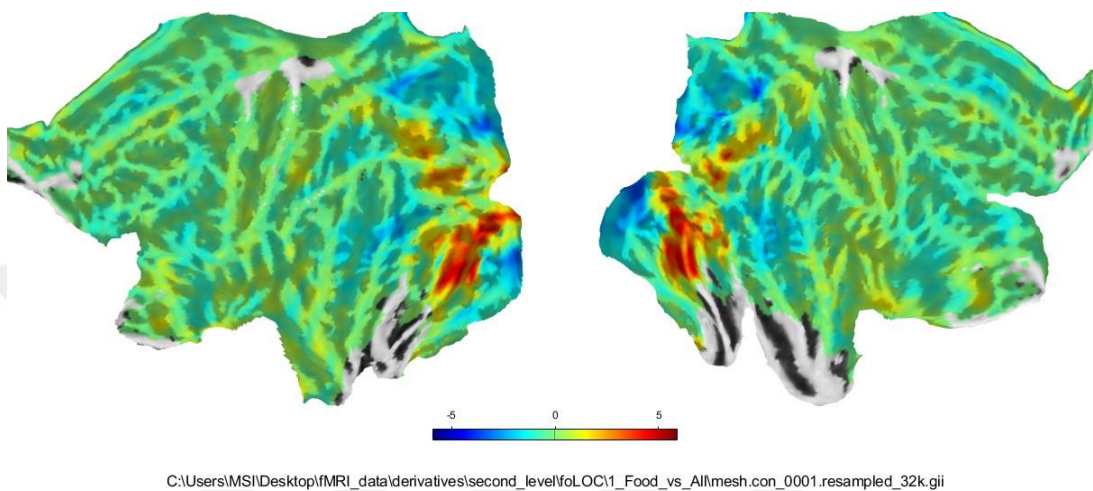


Figure A.1: Food vs All on the Flat Brain. Group Level Neural Responses to Food vs All contrast overlayed on the flat brain

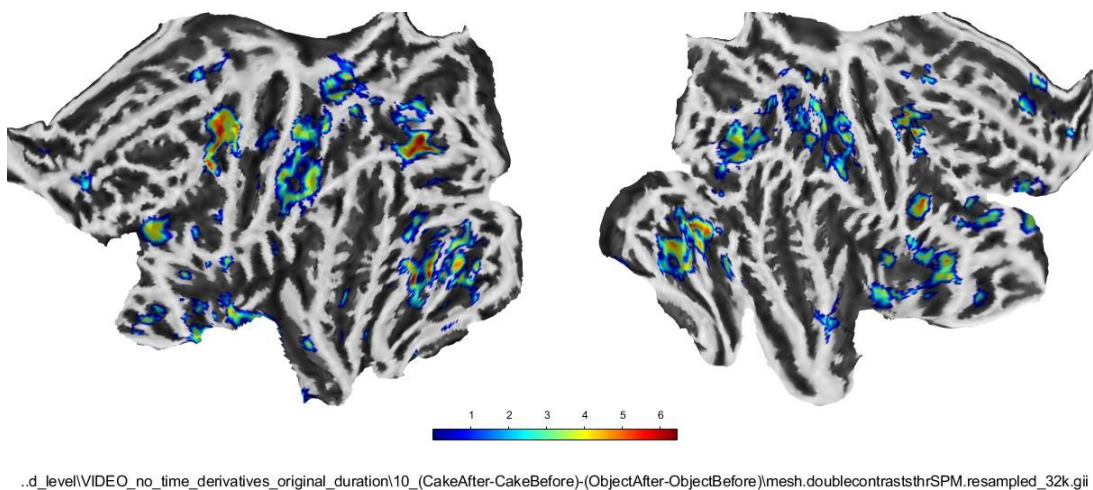


Figure A.2: Double Contrast on the Flat Brain. (Cake After Knife-Cake Before Knife)-(Object After Knife - Object Before Knife) on the flat brain

Table A.5: SPM Results Table: (Object After Knife – Object Before Knife)

Cluster-level				Peak-level					
p(FWE)	p(FDR)	k	p(unc)	p(FWE)	p(FDR)	T	Z	p(unc)	x, y, z (mm)
0.955	0.613	60	0.043	0.980	0.908	5.13	3.78	0.000	-22, -47, 28
				1.000	0.944	3.35	2.82	0.002	-14, -42, 18
				1.000	0.944	3.03	2.61	0.004	-10, -34, 12
				1.000	0.944	2.90	2.53	0.006	-17, -40, 20
				1.000	0.944	2.82	2.47	0.007	-20, -32, 15
0.205	0.138	148	0.003	0.994	0.908	4.90	3.68	0.000	-2, -37, 8
				0.999	0.908	4.67	3.57	0.000	28, -54, 15
				1.000	0.908	4.56	3.51	0.000	0, -30, 5
				1.000	0.944	3.36	2.83	0.002	-2, -47, 12
				1.000	0.944	3.17	2.71	0.003	20, -40, 18
				1.000	0.944	3.15	2.69	0.004	13, -34, 12

Summary: Table shows 16 local maxima more than 4.0 mm apart.

Thresholds and Image Properties: *Height threshold:* $T = 2.62$, $p = 0.010$ (1.000); *Extent threshold:* $k = 5$ voxels, $p = 0.548$ (1.000)

$\langle k \rangle = 14.220$ voxels; $\langle c \rangle = 39.92$ clusters; $FWE_p = 8.133$; $FDR_p = \text{Inf}$; $FWE_c = \text{Inf}$; $FDR_c = \text{Inf}$

$df = [1.0, 14.0]$; $FWHM = 10.2 \times 10.3 \times 9.8$ mm ($4.1 \times 4.1 \times 3.9$ voxels); $Volume = 1,383,859$ mm³ = 88,567 voxels = 1,215.7 resels; $Voxelsize = 2.5$ mm³ (1 resel = 66.60 voxels)