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ABSTRACT

Electroencephalography (EEG), and the measure of event-related potentials (ERPs) in particular, are useful methods to study the cognitive and cerebral mechanisms underlying the perception and processing of food cues. Further research on these aspects is necessary to better understand how cognitive functioning may influence food choices in different populations (e.g. obese individuals, individuals with eating disorders). To help researchers in designing future studies, this article provides an overview of the methods used in the current literature on ERPs and food-related cognition. Several methodological aspects are explored to outline interesting perspectives for future research, including discussions on the main experimental tasks used, the cognitive functions assessed (e.g. inhibitory control, attentional processing), the characteristics of the participants recruited (e.g. weight status, eating behaviors), and the stimuli selected (e.g. food pictures, odors). The issues generated by some of these methodological choices are discussed, and a few guidelines are provided.

1. Introduction

Food choices are guided by both conscious and non-conscious processes (Jacquier et al., 2012; Papies, 2016; Sheeran & Gollwitzer, 2012). Cognitive functioning, in particular, may influence dietary decisions depending on various factors such as weight status, dieting history, or eating disorders (for reviews, see Carbine et al., 2018; Chami et al., 2019). To better understand food-choice decisions in different healthy and pathological populations, further research is needed on the cerebral mechanisms underlying the perception and processing of food cues. For this purpose, electroencephalography (EEG) is an appropriate method to explore the brain responses to food stimuli, from non-conscious and automatic processes to conscious and motivated ones. In this review, we will focus on event-related potentials (ERPs), which is the most commonly used method of analysis of EEG data.

EEG is a non-invasive electrophysiological method for recording the electrical activity of the brain over a period of time. It directly records the summed electrical activity of large groups of neurons with a millisecond-range temporal resolution. The recording is done by placing several electrodes on the scalp with a conductive gel, directly on the skin or by using a cap. The number of electrodes varies depending on the research needs, as adding electrodes increases the spatial resolution. The most common analysis of EEG recordings is the ERP analysis. An ERP is the resulting combined brain activities that are evoked in response to a specific stimulus or event (e.g. pictures, odors, sounds). As ERPs have very small amplitudes (measured in microvolts), they cannot be directly observed within the raw EEG recording (Teplan, 2002). For analysis, short recording periods (epochs) that are time-locked to a specific stimulus need to be extracted from the continuous EEG recording and averaged (Beres, 2017). To reduce noise and increase the signal of interest, the same stimulation needs to be repeated many times. There is no definitive recommendation for the number of repetitions, except that the more repetitions, the better the signal-to-noise ratio. However, the ideal number of repetitions is influenced by the nature of the stimuli. For visual and auditory stimuli, about 80–100 repetitions are commonly recorded. Odor and taste stimuli roughly require about 40–60 repetitions. The averaging of the epochs then results in an ERP wave that reflects the neuronal activity evoked by the repeated presentation of a specific stimulus.

ERP waveforms are composed of several positive and negative deflections called peaks or components and associated with different brain functions (see Fig. 1). Although both terms are often used interchangeably across the literature, they actually refer to different concepts. The term "peak" specifically refers to the time at which the ERP voltage reaches a maximum amplitude in a defined time window. On the other hand, the term "component" rather refers to the underlying

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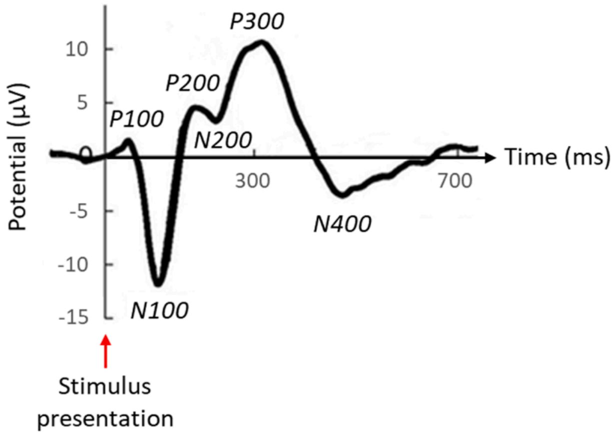

Fig. 1. Schematic ERP displaying several peaks (P100, N100, P200, N200, P300, and N400). The "time 0" corresponds to the beginning of the stimulation. Each peak reflects a major step in brain processing.

perceptive and cognitive functions, which may not be limited to the peak (Luck, 2018). The peaks are usually labeled based on their polarity ('P' for positive, 'N' for negative) and their latency in milliseconds (e.g. P300 is the positive peak appearing around 300 ms after the onset of the stimulus). The early components (latency < 200 ms) are usually associated with automatic bottom-up processes (e.g. sensory processing, early attention; Ferrari et al., 2008). As these early peaks are linked with low-level perception, they should be elicited by every perceptual stimulus such as a word or a picture (Beres, 2017). Later components (latency ≥ 200 ms) are thought to reflect more top-down cognitive processes (e.g. motivated attention, inhibition, working memory; Svaldi et al., 2010), and can be elicited in certain experimental conditions (Beres, 2017). Higher-order cognitive functions can be implemented either in an automatic or controlled way, depending on different parameters (e.g. contextual cues, expectations, personal motivations). In ERP research, it is commonly admitted that the later the peak studied, the more it should involve controlled processes. Thus, due to the excellent temporal resolution of EEG, ERPs are useful to assess the different steps of information processing over time, from early and automatic processes to controlled operations (Sur & Sinha, 2009).

When testing a hypothesis about a particular ERP peak, different parameters can be extracted from ERP data. The most common are peak amplitude and peak latency. The peak amplitude (in microvolts) is defined by the maximum or minimum voltage observed within a time period (Luck, 2018). The amplitude reflects the size of the population of synchronously activated neurons, which gives information about the ongoing perceptual or cognitive processes: the higher the amplitude of a peak, the more neurons are recruited to carry out the processes associated with that peak (e.g. orientation of attention, inhibition). Depending on the cognitive function assessed, a higher peak amplitude is generally interpreted as reflecting increased processing of stimuli or increased effort on the part of the individual to implement the functions necessary to perform the task. The peak latency (in milliseconds) is the time it takes for the peak to reach its maximum from the onset of the stimulus. It provides information about the temporal dynamics of perceptive and cognitive operations (Liesefeld, 2018). The latency duration then reflects the complexity of the neuronal activations necessary for the implementation of different processes: the longer the latency, the greater the number of activated synapses.

In summary, ERPs are measured to study the sensory and cognitive processing of a well-defined stimulus or event. The amplitude and latency of ERP peaks can be used to assess the brain functions involved in processing information and/or performing a task. These last decades, ERPs have been used in cognitive psychology and neurosciences to test various brain functions, such as sensory perception, executive functions, memory, or language. ERP studies focusing on the processing of food cues (e.g. food pictures or odors) are rather recent. Overall, the available data suggest that attentional processes and executive functions, such as inhibitory control or working memory, are influenced by food cues. How our brain detects and processes food cues in the environment may contribute to our attraction to some foods, and consequently to our food-choice decisions. Research on the neurophysiological activity underlying food-related cognition is gaining more interest lately, since unhealthy eating habits are increasingly associated with weight gain and various health issues, such as cardiovascular diseases, diabetes, or cancer (Kumanyika et al., 2002; Meegan et al., 2017; Rahati & Shahraki, 2014; Walker, 2013).

Two systematic literature reviews have already been published on the results reported in the literature on ERPs and food-related cognition (Carbine et al., 2018; Chami et al., 2019). The purpose of the current narrative review is to go beyond the existing state of the art by discussing the methods used in this literature and by giving some methodological guidance. In the following sections, we will explore several methodological aspects to outline interesting perspectives for future research on ERPs and food-related cognition. We will review the main tasks used, the characteristics of the participants recruited, the stimuli used and the experimental conditions compared. We will discuss the issues generated by some of these methodological choices, and highlight the gaps in the literature. Thus, the current article is intended to help researchers in designing future ERP studies on food-related cognition, by discussing possible improvements and new perspectives.

However, we will not go into detail about the EEG method and all the parameters to be taken into account when recording and processing ERPs. An extensive discussion of these aspects would be too broad for the topic of this review, and this has been done elsewhere (Luck, 2014). There are numerous parameters to consider when developing a task in which ERPs will be measured, such as stimulus presentation time, number of trials, stimulus-onset delay and reaction time frame. The decisions to be made depend on the type of task, the type of stimuli and the components measured, in order to optimize the signal-to-noise ratio. There is also a significant degree of freedom in the methods used to process ERP data, from pre-processing to statistical analysis. For the readers interested in those technical aspects, we strongly recommend the reference book by Luck (2014).

Throughout the review, we will provide examples of studies from the literature on ERPs and food related-cognition. These examples were selected among the articles included in the previously cited reviews (Carbine et al., 2018; Chami et al., 2019), and completed by an updated literature search for publications since 2019 on PsycInfo (EBSCO) and PubMed. We used the same search terms as Carbine et al. (2018): *("event-related potentials" OR ERPs OR "evoked potentials" OR electrophys*) AND (food* OR eat* OR diet*) NOT (rodents OR rats OR mice OR animals) NOT (infants OR child OR children)*. We focused on studies including adult subjects only, as they represent the most studied population at present. Some articles have been published on children, adolescents, and older adults, but they are beyond the scope of the present review. Further research on these populations should however be encouraged, as few data is currently available.

2. Type of tasks

To study the variety of cognitive functions that may underly eating behavior, several experimental paradigms have been developed. In this section, we will present the most common tasks that have already been used for studying food-related cognition with ERPs: passive viewing tasks, oddball paradigms, Go/No-Go paradigms, evaluation/rating tasks, conditioning paradigms, modified Stroop tasks, and working memory tasks. All of them are inspired by classic paradigms created to study cognitive functions in general and have been adapted to study food-related cognition. We will describe each task, define their interest, provide some examples from the literature, and discuss their limits. In the last subsection, we will summarize some important points and discuss perspectives for future paradigms.

2.1. Passive viewing tasks

In passive viewing tasks, the participant is asked to simply attend to visual stimuli (e.g. pictures, words) on a screen. She/he is specifically told not to apply a particular mental operation towards the stimuli. In conjunction with ERPs, these tasks are usually used to study early and late attentional processes. Early attentional processes are assessed by measuring the amplitude of ERP peaks with latencies $\leq$ 200 ms, such as the P100, N100, P200, and N200. The P200 and N200 are sometimes defined as 'mid-latency' components, in opposition to very early peaks with latencies $\leq$ 100 ms. Late attentional processes are usually assessed with the P300 peak and the *late positive potential* (LPP), which is a positive wave beginning around 400 ms after stimulus onset.

Passive viewing tasks are the most common tasks in the literature on ERPs, food stimuli, and cognition (Becker et al., 2016; Blechert et al., 2010; Hanlon et al., 2012; Nijs et al., 2008; Schwab et al., 2017; Stockburger et al., 2008; Stockburger, Renner, et al., 2009; Stockburger, Schmälzle, et al., 2009; Versace et al., 2015). For instance, some researchers used passive viewing tasks to compare the cerebral processing of food pictures and pictures of non-edible objects (e.g. office items, flowers). They reported larger amplitudes of the P300 and LPP for food pictures, suggesting a greater allocation of attentional resources for processing food information compared with non-food-related information (Carbine, Larson, et al., 2017; Nijs et al., 2008). Nijs et al. (2008) concluded that this result reflects the strong motivational value of food.

Passive viewing can also be used to study the conflict between two sensory modalities. For example, Schwab et al. (2017) were interested in the influence of disgust on the cerebral processing of visual food cues. They created a conflict between two senses, taste and sight: their participants were instructed to rinse their mouths with a bitter beverage (or water as control) before passively watching pictures of sweets, meats, and vegetables. The results showed that the perception of bitterness increased early attention (N100, N200) for all foods (Schwab et al., 2017).

Thus, passive viewing tasks are useful to highlight visual perceptual mechanisms, attentional processes, and conflict monitoring. The cerebral activity for different categories of stimuli (e.g. food, non-food) can easily be compared. These tasks are also easy to perform and do not require any particular training. However, the fact that attention is not focused on a specific activity can make these tasks monotonous to perform, which might increase cerebral noise. Indeed, a boring task can lead to the appearance of alpha brain waves, a type of brain signal which is characteristic of a loss of concentration or fatigue (Luck, 2005). Although alpha activity is a common artifact in EEG data, it is rather tricky to remove once recorded (Vanderperren et al., 2009). To reduce such a phenomenon, including regular breaks during the sessions is necessary to relax the participants, refocus their attention, and reduce boredom.

2.2. Oddball paradigms

The oddball paradigm is commonly used for attention measurement in ERP studies because it reliably induces a P300 component. In this paradigm, repetitive presentations of a standard stimulus are infrequently and randomly interrupted by a deviant/target stimulus (the "oddball" stimulus). The stimuli used are usually pictures or sounds. There are two variations of this paradigm: the active and the passive paradigm. In the active paradigm, the subjects are instructed to respond to the target stimulus, usually by pressing a button or counting its apparitions. In the passive paradigms, the participants are asked to simply attend to the stimuli repetitions without giving responses. In combination with EEG recording, the ERPs induced by the target stimulus are recorded.

For example, Babiloni and colleagues adapted the visual oddball paradigm to assess the attentional cortical responses to enlarged faces and foods in different populations (e.g. dieters, obese individuals; (Babiloni, Del Percio, De Rosas, et al., 2009; Babiloni, Del Percio, Triggiani, Marzano, Valenzano, De Rosas, et al., 2011; Babiloni, Del Percio, Triggiani, Marzano, Valenzano, Petito, et al., 2011; Babiloni, Del Percio, Valenzano, et al., 2009). They used the same task across four studies. This task included pictures of faces, foods, and landscapes as standard stimuli (70% of the presentations) and the same pictures that were horizontally dilated by 25% as deviant stimuli (30% of the presentations). The subjects were asked to click for the deviant stimuli, and the P300 peak elicited by the deviant stimuli was measured. One result suggests that the amplitude of medial prefrontal P300 sources is lower in obese than normal-weight subjects for food pictures (Babiloni, Del Percio, Valenzano, et al., 2009). The authors concluded that prefrontal attentional processes to food size may be altered in obese subjects.

Another example of an oddball paradigm adapted to study food-related processes comes from Kong et al. (2015). These authors created a two-choice oddball task to test the impact of restrained eating on inhibition in front of food. Restrained eating refers to the voluntary restriction of food intake, in order to lose weight or prevent weight gain. In this task, the standard stimulus was a picture of a steel clock, infrequently interrupted by the presentation of 3 types of deviant stimuli: pictures of low-energy foods, high-energy foods, and "neutral" pictures (the content of the neutral pictures is not provided in the paper). The participants were asked to press one key for the standard stimuli presentations, and another key for the deviant stimuli presentations. The ERPs elicited by the deviant stimuli were measured, and three peaks were analyzed: the N200 (as an indicator of conflict detection), the P200 (sensory processing), and the P300 (attentional processing). One result obtained with this paradigm was that the P200 latency was shorter for high-energy food pictures than for neutral pictures, in successful restrained eaters only (i.e. who successfully manage to regulate their food intake). This suggests that successful restrained eaters may be more reactive to high-energy food cues, compared with unsuccessful restrained eaters.

Thus, oddball tasks can be used in combination with ERP recording to assess attentional processing (e.g. P300, P200), but also other functions such as conflict detection (N200). However, it is important to note that the attentional processes measured in oddball tasks are associated with deviance processing, as the expectation of a standard stimulus is violated by an unexpected deviant stimulus (Schlossmacher et al., 2020). The detection of deviations from regularities of the sensory input is important to react to changes in the environment. Thus, the interpretation of the ERP components measured in oddball tasks may differ from those assessed with other tasks measuring attention (e.g. passive viewing tasks). By using various food cues as deviant stimuli, oddball tasks are interesting to study how the brain detects and processes unexpected food cues in different experimental environments.

2.3. Go/No-Go paradigms

Go/No-Go paradigms are used to test inhibitory control, which is an executive function allowing to control one's behavior, thoughts, or emotions, to override internal predispositions or external influences (Diamond, 2013). In Go/No-Go tasks, series of stimuli are continuously presented to the participants, who are instructed to perform a quick motor response (e.g. pressing a button as fast as possible) when certain stimuli ("Go" cues) are displayed, and to withhold any reaction for other stimuli ("No-Go" cues; Meule, 2017). The classic Go/No-Go task involves more "Go" cues ($\geq$75%) than "No-Go" cues. The theory behind is that a higher frequency of "Go" cues is necessary to create a prepotent tendency to respond, which must be inhibited for "No-Go" cues. Thus, participants' capacity to inhibit their responses is tested, as well as sustained attention and impulsiveness (Meule, 2017). Commission errors (i.e. falsely pressing the button in "No-Go" trials) are usually measured as a behavioral indicator of inhibition difficulties. From a neural perspective, the N200 component is usually measured as an indicator of inhibitory control processes, since its amplitude is larger when withholding a dominant response (Folstein & Van Petten, 2008).

Some data suggest that using an equiprobable variant of the Go/No-Go task (with a 50/50 split of "Go" and "No-Go" trials) reliably produces a N200 response in "No-Go" trials, which allows the assessment of response inhibition similarly to the classic Go/No-Go task (Aulbach et al., 2020). To our knowledge, there is no study that directly compared the N200 peak obtained in the classic task with the one observed in the equiprobable variant of the task. We may wonder whether the inhibitory response would be weaker in the equiprobable variant, but this remains to be tested.

Go/No-Go tasks have been adapted to study the neural correlates of inhibitory control and impulsive reactions toward food cues (Aulbach et al., 2020; Carbine, Christensen, et al., 2017; Lapenta et al., 2014; Watson & Garvey, 2013). For example, Carbine and colleagues presented pictures of high- and low-calorie foods to their participants in two tasks: the high-calorie foods were specified as the "Go" cues in one task, and as the "No-Go" cues in the other task (Carbine, Christensen, et al., 2017). The results showed that inhibiting responses towards high-calorie foods produced a greater N200 amplitude than for low-calorie foods, suggesting that the participants had to recruit more cognitive resources to inhibit their response toward high-calorie foods. The authors also reported a significant correlation between the N200 amplitude and the reported daily calorie intake, suggesting that food-related inhibitory control may be linked to later eating behavior. In another study, Watson and Gavey also used a Go/No-Go paradigm to assess the involuntary orienting of attention toward distracting stimuli, by measuring the "No-Go" P300 peak (Watson & Garvey, 2013).

In summary, combining Go/No-Go paradigms with ERP recording is particularly useful to study food-related inhibitory control by measuring the N200 peak. This method can also be used to study attentional processes, by assessing peaks such as the P300. By manipulating the nature of the "Go" and "No-Go" cues, the inhibitory responses can be compared for various types of foods, or in comparison with non-edible items. Such paradigms can also help to assess mental flexibility toward food cues, by alternating the "Go" and "No-Go" cues in two consecutive tasks (e.g. specifying high-calorie foods as "Go" cues in one task, and as "No-Go" cues in another task). Moreover, as deficits in inhibitory circuits have been associated with a compulsion for food (Lapenta et al., 2014; Uher et al., 2004), further research is needed on inhibitory function in populations with overeating disorders, overweight, and obesity. Finally, Go/No-Go paradigms are easy to implement, but they present a couple of disadvantages. First, they require a high number of trials, which increases session duration and can induce boredom. These tasks can also be a bit complex to perform at first and require a short training session.

2.4. *Evaluation/rating tasks*

We use the terms "evaluation tasks" or "rating tasks" to refer to the tasks where the participants are asked to rate stimuli (e.g. pictures, words) according to their knowledge or personal opinion. For each stimulus, they have to select one response between several response options. There is no unique structure for these tasks since they are developed to answer various experimental needs.

For example, Feig et al. (2017) investigated the relationship of dieting history and hunger state with the neural responses to visual food cues. They compared the cerebral activity of "historical dieters" (with a history of dieting with the intent of weight loss) to "never-dieters" (who have never gone on a diet to lose weight). ERPs were recorded while the participants rated a series of food pictures as "delicious" (left button of the computer mouse) or "not delicious" (right button). The task was done twice by the participants, once when hungry and once when full. For data analysis, the pictures were gathered in two hedonic categories (high vs. low hedonic value) based on participants' ratings, to test for a "hedonic effect" of neural response. Six ERP peaks were analyzed for exploratory purposes (P100, N100, P200, N200, P300, LPP). The results showed no significant interaction between dieting history and hedonic value on any peak amplitudes, but several other results were reported. For example, historical dieters presented larger LPP mean amplitudes when fasting compared to fed, suggesting increased conscious attention to food cues when fasting.

In the ERP literature on food-related cognition, rating tasks have been mainly used to study the attentional processing of food cues, with the measure of various components such as the P100, N100, P200, N200, P300, and LPP (Feig et al., 2017; Harris et al., 2013; Ma et al., 2014). Rating tasks represent an interesting method to categorize the food stimuli based on the personal opinion or knowledge of the subjects for later ERP analysis. For example, the food stimuli can be categorized based on personal taste (e.g. liked vs. disliked foods), opinions on the healthiness of the foods (e.g. healthy vs. unhealthy), or knowledge about their caloric content (e.g. high vs. low-calorie). However, the fact that the stimuli gathered in each category could differ across participants can raise a potential problem: the ERPs measured may not only reflect the processing of different categories of interest (e.g. liked vs. disliked foods), but also perceptual differences between stimuli selection in each category (e.g. picture brightness or complexity). Such confounding effects are expected to be stronger in early peaks such as the P100 and N100, which are associated with pre-attentive sensory processing (Hume et al., 2015). Later peaks reflecting more top-down processes should be less influenced by sensory parameters. In all cases, we recommend pre-testing the stimuli in a dedicated sensory evaluation test to ensure that they differ only on one variable of interest. A more detailed discussion on the parameters to control when selecting stimuli is available in section "4. Stimuli".

Additionally, as the number of stimuli that will be included in each category can not be perfectly predicted, there is a risk of obtaining a lot of variability in the number of stimuli across categories and subjects. To allow ERP analysis, the stimuli have to be selected in large quantities to ensure a sufficient number of stimuli by category after participants' ratings. The answers of the subjects can also be nuanced with continuous rating scales where responses are scored along one perceptual dimension, like Likert-type scales, numeric rating scales, or verbal rating scales. Finally, rating tasks are also useful to assess the influence of various parameters on the participants' evaluation of food cues, such as dieting history or physiological state (e.g. hunger, thirst).

2.5. *Conditioning paradigms*

In combination with ERP recording, conditioning paradigms are traditionally used to investigate the neural substrates of learning and memory. In these paradigms, the subjects learn an association between two stimuli: a neutral stimulus and an unconditioned stimulus that triggers a specific behavioral, physiological, or cerebral response. When the learning is completed, the initially neutral stimulus becomes the conditioned stimulus: its perception triggers the same responses as the unconditioned stimulus.

We found a couple of studies measuring ERPs during a taste conditioning task (Franken et al., 2011; Viemose et al., 2013). For example, Franken et al. (2011) investigated the neural correlates of appetitive conditioning. In their study, they assessed the electrophysiological response to visual stimuli that were conditioned with a taste reward (i.e. a sweet fluid). They used a conditioning paradigm where a picture of a blue square and a picture of a red circle (neutral stimuli) were paired either with a sweet or a neutral fluid directly delivered in the mouth (unconditioned stimuli). The presentations of the visual and taste stimuli were not simultaneous, as fluid delivery followed picture presentation in each trial. The authors separately measured the ERPs elicited by taste stimuli and the ERPs elicited by taste-conditioned stimuli (i.e. the pictures). They reported that the sweet taste elicited larger P100 and P300 peaks than the neutral taste, highlighting the motivational value of the sweet taste. They also observed an enhanced P300 response to the pictures paired with the sweet fluid, as compared to the ones coupled with the neutral taste. To explain this result, the authors argued that the neutral pictures may have acquired motivational relevance during the conditioning.

Thus, coupling conditioning paradigms with ERP measurements is useful to study the impact of associative learning between two stimuli on brain activity. The few studies using such paradigms focused on appetitive conditioning, and their results suggested that taste conditioning influences the cerebral processing of pictures (Franken et al., 2011; Viemose et al., 2013). The peaks measured were linked to attentional processes, with a particular interest in motivated attention. Available data shows that ERPs can be used to differentiate between visual stimuli paired with a sweet taste and a neutral taste, but the effects of other types of taste (e.g. salty, sour, bitter, umami), which differ in nutrient content and pleasantness, are yet unknown. Studies on these aspects may also contribute to a better understanding of several psychopathological conditions where appetitive conditioning is altered, such as eating disorders, substance abuse, and depression (Martin-Soelch et al., 2007). In addition, other associations of food-related stimuli from different sensory modalities remain to be explored (e.g. pictures/odors, textures/tastes).

In the cited studies, the authors compared the ERPs elicited by the pictures before and after they were associated with tastes. It is therefore the outcomes of the conditioning that are evaluated, not the learning process itself. It would be interesting for future research to measure ERPs during encoding to better understand how the association between two stimuli modifies brain activity, and what impact these modifications have on the later processing of conditioned stimuli. For example, Wiemer et al. (2021) studied associative fear learning between pictures depicting neutral facial expressions (neutral stimulus) associated with either an aversive outcome (unconditioned stimulus) or no outcome. The ERPs elicited by the pictures were recorded during learning. The results showed that an enhanced P300 during learning predicted subsequent memory for the pictures associated with the aversive outcome, but not for the other pictures. It suggests that an increased P300 during associative learning could be a marker of improved detection of potentially threatening stimuli later on. In research on food-related cognition, the observation of a distinctive brain activity during associative learning between two food-related stimuli could generate a particular processing of the conditioned stimulus afterwards. This could possibly explain the attraction or disinterest for certain foods for example.

Another interesting avenue for future research would be to use ERPs to study the time course of associative learning during conditioning until learning is complete. The main difficulty in implementing such a method is that many stimulus repetitions are required to obtain analyzable ERPs, which does not allow a precise analysis of the progressive evolution of the components' amplitude or latency over time. To get an overview of the evolution of brain activity during learning, the ERPs recorded for each stimulus presentation during conditioning could be aggregated to reflect different stages of the learning process and compared.

Finally, in the context of food science, a limit to the investigation of the associative learning between stimuli may rely on the nature of food-related stimuli. Food-related stimuli such as tastes or odors are indeed more difficult to manipulate than pictures, especially in experimental settings where the trials follow one another quickly. Dedicated stimulating devices with high time resolution are useful in this context and training of the subjects is highly recommended.

2.6. Modified Stroop tasks

The classic Stroop task (Stroop, 1935) is used to investigate cognitive interference, by creating a conflict between two incongruent pieces of information. Participants are presented with color words displayed in various font colors: a font color that corresponds to the actual word (match condition; e.g. the word "blue" written in blue) and other colors that do not correspond (mismatch condition; e.g. the word "blue" written in green). Participants are instructed to name the color of the font for each word. In the mismatch condition, subjects take longer to name the font color, compared to the match condition. This phenomenon is called the Stroop effect and reflects cognitive interference between two pieces of information. The Stroop effect is usually measured to investigate selective attention and inhibitory function.

The emotional Stroop task is a well-known variation of the classic Stroop task, and it is actually more closely related to the modified Stroop tasks currently used to study food-related cognition. In the emotional Stroop task, the words presented either refer to emotional states (e.g. panic, love), or they are "neutral" (i.e. not associated with emotional states; for example: building, book). Like in the classic Stroop task, the participants are instructed to name the color of the font for each word. Longer response times for emotional words than for neutral words suggest that the participants are affected by the emotional content conveyed by the words, even though it is irrelevant to the color-naming task. This phenomenon is called the emotional Stroop effect. Contrary to the classic Stroop task, the two pieces of information manipulated here to create cognitive interference (word meaning and font color of the word) are not semantically linked, as the words are not color-related. The interference effects observed (i.e. slower reaction times) may not reflect a conflict between word meaning and font color, but an increased attentional capture due to the relevance of the word for the individual. The few ERP studies that have adapted the Stroop task to examine food-related cognition have used food words presented in different colors as stimuli (Hume et al., 2015; Nijs, Franken, et al., 2010). As in the emotional Stroop task, the words are not semantically related to the font color. The mechanism studied would therefore be the interference created by automatic attentional capture in favor of food stimuli, not the conflict created by two incongruent pieces of information, like in the classic Stroop task.

For example, Nijs et al. (2010) used a modified Stroop task to study differences in brain processing of food-related words between obese and normal-weight subjects. They measured reaction times and neurophysiological indices (P200 and P300 peaks). The subjects viewed words referring to palatable foods (e.g. chocolate, hamburger) and office-related words (e.g. tape, paperclip, ball pen), referred to as "neutral" words. The words were presented four times, each time in a different color (blue, red, yellow, and green). The participants were instructed to indicate as fast as possible the font color of the words by pressing a button in the corresponding color. A larger P200 amplitude was reported for food-related words in obese subjects compared with normal-weight subjects, indicating an increased attentional bias toward food words on the automatic level. The P300 amplitude was also larger for food than neutral words for both groups, suggesting a general bias in conscious attention to food words (Nijs, Franken, et al., 2010).

Thus, the Stroop task can be easily adapted to study the neurophysiological correlates of attentional capture by food cues through the measure of various ERP components (e.g. P150, N150, P200, P300, LPP; Hume et al., 2015; Nijs, Franken, et al., 2010). However, new methodologies could be developed to investigate the neural correlates of conflict processing between incongruent food cues. In this context, the main limitation of the Stroop task is that it involves only visual stimuli, and food cues are multimodal. For example, congruent and incongruent food pictures and food words may be combined to create interference in a modified Stroop task, but it will be more difficult to include other types of food-related stimuli, such as odors. In our opinion, the Stroop task is not well adapted to study the cognitive interference created by incongruent information coming from different sensory sources. New tasks should be designed to allow us to better understand how the brain manages the conflict between different sensory sources when the perceived information is food-related.

2.7. Working memory tasks

Working memory is a cognitive system that can hold information temporarily for further manipulation, with limited capacity. In the tasks investigating working memory, the subjects are instructed to hold one or several items in memory. After a variable delay period, they are asked either to recognize the previously presented items among other items (recognition task) or to retrieve as many of the previously learned items as possible (recall task). Combined with ERPs, these tasks are useful to investigate the neural markers of working memory for different stimuli in various populations.

A couple of studies used ERP measurements to investigate the neural representation of food items in working memory (Pietrowsky et al., 1994; Rutters et al., 2015). For example, Rutters et al. (2015) presented food and non-food pictures (including cars and stationery items) to their participants, who were instructed to hold the pictures in memory for a subsequent recognition memory test. They measured three ERP components associated with attention, memory, and retention of memory: the P300, the LPP, and the *Sustained Posterior Contralateral Negativity* (SPCN), a negative slow ERP component appearing after 600 ms post-stimulus. All the components measured were larger when food items were held in working memory compared with non-food items, suggesting a stronger representation of food in working memory (Rutters et al., 2015). The processing of food-related information in working memory may thus influence the deployment of attention toward food cues.

Several ERP components can be investigated during stimuli memorization (e.g. N100, P200, N200, P300, LPP, SPCN; Pietrowsky et al., 1994; Rutters et al., 2015). Working memory tasks are useful to measure and compare the neural correlates of memory for different types of food and non-food stimuli, in different populations (e.g. individuals with various weight statuses, or eating disorders). In the cited studies, the items to remember were only visual stimuli (pictures, words), but such tasks could be adapted in the future to study the memory of food stimuli from different sensory modalities (e.g. odors, sounds).

2.8. Tasks: Summary and perspectives

We previously described the most common tasks in the current literature on ERPs and food-related cognition, which are based on well-known paradigms from cognitive psychology. These tasks have been mainly used to study the neurophysiological correlates of attentional processes concerning visual food stimuli (see Table 1 for a summary). Attention can indeed be assessed with most tasks, as the deployment of attention is a prerequisite to all further cognitive processing. The peaks usually measured to assess early attention are the P100, N100, P200, and N200, and the ones associated with late attention are the P300 and LPP. Inhibitory control is the second most studied function, mainly by using Go/No-Go tasks but also with the oddball paradigm in at least one study (Kong et al., 2015). The N200 peak is usually measured as an early neural marker of response inhibition: the higher its amplitude, the greater the involvement of neuronal resources for inhibiting the response. Memory and decision-making have also been assessed in a few ERPs studies using food stimuli.

Table 1
Summary of the cognitive functions and peaks studied in the main tasks used in the current literature on ERPs and food-related cognition.

Type of tasks	Cognitive functions assessed	Peaks measured
Passive viewing tasks	Attentional processes	P100, N100, P200, N200, P300, LPP
Oddball paradigms	Attentional processes	P200, N200, P300
Go/No-Go paradigms	Inhibitory control Attentional processes	N200, P300
Evaluation/rating tasks	Attentional processes	P100, N100, P200, N200, P300, LPP
Conditioning paradigms	Associative learning Memory Attentional processes	P100, N100, P200,N200, P300
Modified Stroop tasks	Cognitive interference Inhibitory control Attentional processes	P150, N150, P200, P300, LPP
Working memory tasks	Working memory Attentional processes	N100, P200, N200, P300, LPP, SPCN

Of course, research on ERPs and food-related cognition is not limited to these well-known tasks and a variety of other paradigms have been developed to answer specific experimental needs. For example, some original tasks were created to study the cognitive reappraisal of food cues (Sarlo et al., 2013; Svaldi et al., 2015), or to compare the brain activity between imagery and real perception of food pictures (Marmolejo-Ramos et al., 2015). For future research, we would like to encourage the development of food-specific paradigms. One possible direction would be to assess the influence of commensality on the perceptual and cognitive processing of real food. There is still little data on this topic, but one ERP study showed that a restaurant meal eaten in the company of others was more relaxing for the participants and reduced their cognitive control compared to a solitary meal (Sommer et al., 2013). Another interesting line of research would be to study the effects of targeted interventions on the brain processing of food stimuli. For example, Zahedi et al. (2020) tested whether posthypnotic suggestions could increase the desire for low-calorie foods such as vegetables and fruits. By measuring several ERP components (e.g. P100, LPP, N200, P300), they showed that posthypnotic suggestions reduced the perceptual bias towards high-calorie foods and increased motivated attention towards low-calorie foods (Zahedi et al., 2020). These results suggest that posthypnotic suggestions are a promising technique for supporting healthy food choices, calling for further research. In addition, we think that new tasks should also be developed to better simulate the actual interactions that we have with food stimuli on a daily basis.

In particular, we would like to highlight the interest of pursuing research on decision-making but adapted to food stimuli. The cerebral correlates of food decision-making have not been studied much (Harris et al., 2013), although it is often the last step of the cognitive processing of food cues in everyday life. In a Go/No-Go task, Carbine and colleagues observed a significant correlation between the N200 amplitude and the reported daily calorie intake (Carbine, Christensen, et al., 2017). This result suggests that food-related inhibitory control, as assessed with the N200, may be linked to later eating behavior. However, a recent study also using a Go/No-Go paradigm with food pictures reported the opposite result; namely, no correlation between N200 amplitude and calory intake (Aulbach et al., 2020). One main difference between these studies was that calorie intake was directly measured in the latter through a snack break offered to the participants, while it was reported with a questionnaire in the first study. The first study also measured daily food intake, which involves several meals and snacks. We can wonder to what extent these methodological differences in assessing food intake may have influenced the results. These observations call for further research, as the relationship between the neurophysiological activity measured for various cognitive functions (e.g. attention, inhibition, memory) and the subsequent eating behavior is still unclear.

Understanding the mechanisms underlying food choices is primordial to prevent unhealthy eating habits, overeating, and weight gain. It is now accepted that obese individuals display particular cognitive and behavioral profiles, compared with normal-weight individuals. For example, they present an increased attentional bias towards food stimuli, and a deficit in cognitive control (Hendrikse et al., 2015). Several studies also showed differences in brain activity depending on the Body Mass Index (BMI) when processing food stimuli (Babiloni, Del Percio, Triggiani, Marzano, Valenzano, Petito, et al., 2011; Nijs, Muris, et al., 2010; Versace et al., 2015). There is also evidence of an impairment in decision-making in obese individuals, as they make more risky choices than normal-weight individuals (for a review, see Rotge et al., 2017).

However, decision-making has been mainly studied in obesity by using non-food stimuli and gambling tasks, such as the Iowa Gambling Task (IGT).

The IGT was designed to specifically study economic risk-taking (Chandrakumar et al., 2018). Risk-taking is the tendency to voluntarily engage in behaviors with possible undesirable outcomes (Boyer, 2006). In this task, the subjects are asked to accumulate as much virtual money as possible, by picking one card at a time from four decks with various risks of gain and loss. The selection of disadvantageous decks (associated with more losses) is considered as a risky behavior. The peaks commonly measured during the IGT are the *feedback-related negativity*, the *error-related negativity*, and the P300, which are elicited by risk-related decisions or task feedback (for a review, see Chandrakumar et al., 2018). However, we may wonder whether this restricted concept of risk may be generalized to other areas of everyday life, such as health-related decisions (Chandrakumar et al., 2018). In the context of dietary decision-making, some foods are indeed less healthy than others (e.g. high-calorie vs. low-calorie foods); thus, can we consider that some food choices are riskier than others? To do so, we have to assume that the individuals are conscious of the health risks taken by eating some foods, which may not always be the case. In fact, the "healthy behaviors" may not be obvious, particularly in individuals with a lower level of education, which was associated with less nutrition knowledge (Papies, 2016).

There is also evidence that non-conscious and automatic processes play an important role in our food choices (Cohen, 2008; Jacquier et al., 2012; Papies, 2016; Sheeran & Gollwitzer, 2012). Taking a dietary decision implies the processing of different physiological and sensory parameters, such as the level of hunger or the sensory perception of the food. Environmental factors such as social pressure could also influence actual food choices. Thus, in our opinion, the results obtained in obese subjects with gambling tasks can not be directly extended to a real-life food-choice situation. To disentangle the cognitive and neurophysiological mechanisms underlying food decision-making, a challenge for future research would be to develop decision-making tasks properly simulating a food-choice situation. A better understanding of the non-conscious mechanisms that can influence our food choices may help to develop more efficient interventions to improve people's diet.

Finally, we also wanted to encourage the examination of other ERPs through tasks that have not been much explored yet, but that may be associated with food regulation. For example, the *reward positivity* (RewP) is a positive fronto-central component peaking around 200 to 400 ms, reflecting reward processing (Proudfit, 2015). There is evidence that overeating and obesity are associated with an increased reward value of food stimuli, that may facilitate the presence of compulsive-like behavior (García-García et al., 2014). The development of a task involving food rewards and losses may be useful to examine food-related reward processing, with measures such as the RewP, in different populations.

3. Characteristics of the participants

After the overview of several tasks developed to study ERPs and food-related cognition, we will present and discuss the characteristics of the participants recruited in these studies. We will focus on characteristics that may influence the perceptual and cognitive processing of food stimuli. Some of these characteristics are commonly assessed in the study of human cognition, such as gender and age. Other parameters are specific to the study of food-related cognition, such as the body mass index (BMI) of the participants and their eating habits. These characteristics can be assessed as control measures to avoid a confounding effect on the measures of interest, or as factors of interest to test specific hypotheses about differences in brain activity between subject populations (e.g. normal-weight vs. obese individuals). In this section, we will thus discuss some of the characteristics of the participants recruited in the available literature, the interest of measuring these parameters, the methods available to measure them, and possible perspectives for future research. We will review some common demographic characteristics (male/female ratio, age), the measurement of BMI, and the evaluation of pathological and non-pathological eating behavior.

3.1. Male/female ratio

In several studies on ERPs and food-related cognition, the experimenters managed to recruit the same number of men and women as participants (Becker et al., 2016; Leland & Pineda, 2006; Ma et al., 2014; Plihal et al., 2001; Rutters et al., 2015; Stockburger, Renner, et al., 2009; Stockburger, Schmälzle, et al., 2009). However, recruiting more women than men is frequent (Babiloni, Del Percio, Triggiani, Marzano, Valenzano, Petito, et al., 2011; Babiloni, Del Percio, Valenzano, et al., 2009; Benau & Moelter, 2016; Franken et al., 2011; Nijs et al., 2008; Nijs, Franken, et al., 2010; Thomas et al., 2013; Viemose et al., 2013; Watson & Garvey, 2013). The gap between the number of women and men can be substantial, as in one study from Nijs and colleagues, where 32 women were included for 8 men only (Nijs et al., 2008). The opposite – recruiting more men than women – also happens but less frequently (Babiloni, Del Percio, Triggiani, Marzano, Valenzano, De Rosas, et al., 2011; Gable & Harmon-jones, 2010; Harris et al., 2013). In researches focused on obesity, this gender imbalance may be partly explained by the fact that more women are obese than men overall, although gender disparities in excess weight vary across countries (Kanter & Caballero, 2012).

To avoid a potential bias due to gender imbalance in the sample, some authors chose to recruit participants from one gender only: only women (Asmaro et al., 2012; Blechert et al., 2010; Blechert, Goltsche, et al., 2014; Carbine, Larson, et al., 2017; Feig et al., 2017; Hachl et al., 2003; Hanlon et al., 2012; Hume et al., 2015; Kong et al., 2015; Meule et al., 2013; Nijs et al., 2009; Nijs, Muris, et al., 2010; Sarlo et al., 2013; Schwab et al., 2017; Svaldi et al., 2015), or only men (Pietrowsky et al., 1994; Stockburger et al., 2008). Nijs et al. (2010) justify their women-oriented recruitment by the gender differences concerning food craving and eating styles (Braet et al., 2008; Burton et al., 2007). Indeed, it has been shown that women report more cravings than men (Cepeda-benito et al., 2003) and are at higher risk to develop eating disorders (Jacobi et al., 2004).

Such a methodological choice can be a solution to avoid a confounding effect due to the imbalance of the two genders in the sample. However, two other solutions are possible to include participants from both genders and obtain a more representative sample of the population. The first solution would be to include gender as a covariate in the statistical analyses to assess its impact on the measures of interest. The second solution would consist in controlling the characteristics or traits that are suspected to be confounding factors, such as food craving, with specific questionnaires or tests. Based on the results obtained from these measures, the male or female participants behaving differently from the others may be excluded from the sample. If one does not wish to exclude participants, these measures could also be included as covariates in the statistical analyses to control for their possible influence on the measures of interest.

3.2. Age

In a majority of studies on ERPs and food-related cognition, the mean age of the sample is between 20 and 30 years old (Becker et al., 2016; Hume et al., 2015; Schwab et al., 2017; Stockburger, Renner, et al., 2009; Stockburger, Schmälzle, et al., 2009). We noted a couple of studies with a mean age above 30 years old (Hanlon et al., 2012; Versace et al., 2015). When the age range is provided, we can see that the participants recruited are generally between 18 and 42 years old (Babiloni, Del Percio, De Rosas, et al., 2009; Becker et al., 2016; Feig et al., 2017; Franken et al., 2011; Hachl et al., 2003; Harris et al., 2013; Kong et al., 2015; Kumar et al., 2016; Lapenta et al., 2014; Leland & Pineda, 2006; Marmolejo-Ramos et al., 2015; Meule et al., 2013; Nijs et al., 2008; Nijs, Franken, et al., 2010; Pietrowsky et al., 1994; Plihal et al., 2001; Rutters et al., 2015; Sarlo et al., 2013; Stockburger, Renner, et al., 2009). A few studies also included participants aged over 50 years (Babiloni, Del Percio, Triggiani, Marzano, Valenzano, De Rosas, et al., 2011; Carbine, Christensen, et al., 2017; Svaldi et al., 2015; Versace et al., 2015). Thus, the standard deviations in the final samples can be quite large (e.g. above 9 years old; Carbine, Larson, et al., 2017; Hanlon et al., 2012; Versace et al., 2015).

Based on these observations, we would like to highlight possible issues associated with the age criteria used to recruit participants in cognition research. Healthy aging alters several perceptive and cognitive processes, including attentional control, inhibitory control, reasoning, mental flexibility, processing speed, episodic and working memory (for a detailed review, see Harada, Love, & Triebel, 2013). This functional decline is more pronounced after 60 years old, but it is the outcome of a process that is ongoing throughout the whole life. For example, a decline in processing speed begins in the third decade of life, and a decline in inductive reasoning starts around age 45 (Harada et al., 2013). Thus, participants aged from 18 to 60 years old will not display the same cognitive performances, which can be problematic if they are gathered in a supposedly homogeneous experimental group. A large age difference between participants will not introduce random noise, but systematic bias.

A simple way to avoid a confounding effect due to age would be to recruit participants from smaller age ranges (e.g. 18–30 years old). If not possible, age can also be included as a covariate in the statistical model. In the case where the experiment involves dividing the participants into several groups, a good practice would be to control with an appropriate statistical test whether the groups differ or not in terms of age. In addition, we recommend controlling the participants' overall cognitive functioning with appropriate questionnaires. For example, one of the most commonly used questionnaires for older adults is the Mini-Mental State Examination (Folstein et al., 1975). It allows the evaluation of different aspects of cognitive functioning in a few minutes (e.g. attention, calculation, recall, repetition, language).

3.3. *Body mass index (BMI)*

The BMI was developed by Adolphe Quetelet during the 19th century, as a risk indicator of diseases associated with excess adiposity (e.g. cardiovascular diseases, diabetes). This index is used to categorize a person as underweight, normal-weight, overweight, or obese. It is calculated by dividing the body mass (in kilograms) by the square of the body height (in meters), and it is expressed in kg/m^2. The BMI ranges recommended to allocate individuals in one of the four categories have been established by the World Health Organization, and are presented in Table 2 below.

In the available literature on ERPs and food-related cognition, the BMI is mainly used as a control measure to assess that the sample recruited is homogeneous (Becker et al., 2016; Meule et al., 2013; Svaldi et al., 2015; Watson & Garvey, 2013). However, BMI is considered a factor of interest in an increasing number of studies. It can be used as a categorical variable for allocating participants into groups to test differences in neurophysiological activity between underweight, overweight, normal-weight, and obese participants (Babiloni, Del Percio, Triggiani, Marzano, Valenzano, Petito, et al., 2011; Babiloni, Del Percio, Valenzano, et al., 2009; Carbine, Larson, et al., 2017; Hanlon et al., 2012; Hume et al., 2015; Nijs et al., 2008; Nijs, Franken, et al., 2010; Nijs, Muris, et al., 2010; Versace et al., 2015). For example, Hume et al. (2015) compared normal-weight, overweight, and obese women on the amplitude and latency of several ERP components elicited by food and non-food pictures (P150, N150, P200, P300, and LPP). They reported that food pictures led to a larger P200 amplitude in overweight compared with normal-weight women, suggesting a heightened food cue-reactivity in overweight women. A couple of studies did not use distinct BMI groups but used the BMI as a continuous variable, and performed correlation analyses between the participants' BMI and the amplitude of the components measured (Carbine, Christensen, et al., 2017; Kumar et al., 2016).

Table 2
BMI ranges for classification.

Group	BMI range
Underweight	< 18.5
Normal-weight	18.5–25
Overweight	25–30
Obese	> 30

The two BMI-groups that are compared the most are normal-weight and obese groups (Babiloni, Del Percio, Valenzano, et al., 2009; Carbine, Larson, et al., 2017; Hanlon et al., 2012; Nijs et al., 2008; Nijs, Franken, et al., 2010; Nijs, Muris, et al., 2010; Versace et al., 2015). We noticed that overweight and obese subjects are sometimes gathered in one "overweight/obese" group (Babiloni, Del Percio, Valenzano, et al., 2009; Nijs, Muris, et al., 2010). However, overweight and obese persons seem to perform differently on cognitive tasks, although data on this subject is scarce (Mas, Brindisi, Chabanet, Nicklaus, & Chambaron, 2019). For example, there is evidence that only obese adults present a stronger attentional bias toward food pictures in presence of a pound cake odor, compared with a fruity odor (Mas et al., 2019). Therefore, it is reasonable to hypothesize that the neurophysiological activity underlying these cognitive functions may differ as well between obese and overweight subjects. We found only two studies comparing the ERPs of overweight subjects to obese and normal-weight subjects (Hume et al., 2015; Zsoldos et al., 2021), and one study comparing underweight to normal-weight participants (Babiloni, Del Percio, Triggiani, Marzano, Valenzano, Petito, et al., 2011). Thus, little is known on the particular cerebral profiles of overweight and underweight individuals, calling for supplementary research.

An explanation for the issue raised above may be linked to the BMI criteria used to allocate participants in different BMI groups. The ranges provided by the World Health Organization are not always respected, and some studies used their own criteria (Babiloni, Del Percio, Valenzano, et al., 2009; Hanlon et al., 2012; Versace et al., 2015). For example, participants are classified as obese if their BMI is over 25 in at least one study, thus erasing the distinction between overweight and obese individuals (Babiloni, Del Percio, Valenzano, et al., 2009). All individuals with a BMI score below 25 are sometimes considered as normal-weight, including underweight individuals (Hanlon et al., 2012; Versace et al., 2015). We also noticed that the BMI ranges used to create the groups are not always specified (Nijs et al., 2008; Nijs, Franken, et al., 2010; Nijs, Muris, et al., 2010). It is necessary to use the same BMI ranges across studies to make the results obtained comparable.

Moreover, we sometimes observed unreliable ways of measuring BMI, and this issue points out the necessity to provide guidelines to accurately characterize the BMI groups. The BMI is either self-reported by the participants (Nijs et al., 2008; Nijs, Franken, et al., 2010), or assessed by the experimenter during the session (Meule et al., 2013; Nijs, Muris, et al., 2010; Rutters et al., 2015). We also noted that a substantial amount of studies do not describe how the measure was made (Becker et al., 2016; Carbine, Christensen, et al., 2017; Sarlo et al., 2013; Svaldi et al., 2015). However, it is now recognized that self-reports of body weight and height are often inaccurate. A recent study by Burke & Carman highlighted that very thin individuals tend to overstate their weight, and very heavy individuals tend to understate theirs (Burke & Carman, 2017). This phenomenon is mainly due to the social desirability bias; that is, the tendency to answer questions in a socially desirable manner – and it seems that being too thin or too heavy is considered socially undesirable. Thus, we recommend to systematically measure and weigh the participants (i.e. anthropometric measurements) during the experimental session to obtain reliable data.

In summary, BMI is a widely used and easy-to-calculate index to categorize individuals based on their body mass. However, its usefulness has been questioned lately. Excess body fat is significantly associated with increased metabolic risk (Abdelaal et al., 2017; Rahati & Shahraki, 2014), but the association between BMI and body fat is not that clear. There is evidence that other factors, such as age and gender, modulate the relationship between BMI and the percentage of body fat (Meeuwsen et al., 2010). Another issue is that BMI does not distinguish between fat and other body components such as muscle, and as muscle has a higher density than fat, an athlete can sometimes be considered more overweight than a person who does not exercise. The BMI is an easy method to obtain an overview of a person's corpulence in most cases, but its link with health status should be interpreted with caution. A more reliable alternative to BMI would be the direct measurement of body fat, but it requires sophisticated equipment such as bioelectrical impedance analyzers. Another and simpler method consists in measuring the waist-to-height ratio, which has been proved to be a better predictor of cardiometabolic risk factors than BMI (Ashwell & Gibson, 2016; Lee et al., 2008).

3.4. Eating behavior and eating disorders

The term "eating behavior" refers here to all eating habits which are not considered pathological, including restrained eating, emotional eating, external eating, and cravings. Eating disorders are a range of psychological conditions defined by unhealthy eating habits that can negatively affect an individual's physical and/or mental health. They include binge eating disorder (BED), anorexia nervosa, bulimia nervosa, pica, rumination disorder, avoidant/restrictive food intake disorder, and other specified feeding or eating disorders. The criteria for diagnosis are available in the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5; American Psychiatric Association, 2013).

In the literature on ERPs and food-related cognition, assessments of eating behavior and eating disorder symptoms are used in two main ways. First, these measures are often used as inclusion and non-inclusion criteria (e.g. to exclude participants who suffer from eating disorders). Second, these measures are also used to test whether there are differences in brain activity between different populations (e.g. anorexic patients vs. individuals without eating disorders). The purpose of such studies is to assess whether a particular perceptual and cognitive processing of food cues might be associated with the eating behaviors observed in individuals. For example, ERPs can be measured to test whether there is a link between a given behavior and attention to certain foods, or the inhibition processes elicited by certain foods. Attention can be assessed via components such as the P100 or the P300, and inhibition via the N200. The study of food-related cognition in populations with different eating behaviors is of growing interest in the literature (Chami et al., 2019), and patients suffering from eating disorders would benefit from more research to better understand the brain mechanisms underlying unhealthy behaviors (e.g. binge eating).

In the current literature, questionnaires are the main tools for assessing eating behavior and eating disorders. They can be used to assign participants to groups with different behaviors, whose ERPs will then be compared (e.g. restrained vs. unrestrained eaters). Questionnaire scores can also be used as continuous variables to test hypotheses of correlation between a given eating behavior and cognitive functioning, reflected by the amplitude of ERP components. In order to help researchers make choices for their future studies, we will present some of the most frequently used questionnaires to examine pathological and non-pathological eating behaviors. In the following section, the usefulness of these questionnaires will be discussed and their structure will be described (i.e. items, instructions, scoring, psychometric properties). We will also give examples of the use of these questionnaires in the literature on ERPs and food-related cognition, and outline some perspectives for future research. This section will thus provide an overview of different eating behaviors that can be studied with ERPs and the tools that can be used to measure them.

3.4.1. Questionnaires assessing non-pathological eating behavior

In this section, we will provide descriptions of the most used questionnaires to assess non-pathological eating behavior: the Food Craving Questionnaires, the Dutch Eating Behavior Questionnaire, the Three-Factor Eating Questionnaire, and the Restraint Scale.

– *Food Craving Questionnaires* (FCQs; Cepeda-Benito et al., 2000)

The term "craving" initially comes from addiction research and refers to a subjective motivational state promoting substance-seeking and ingestive behaviors (Nijs et al., 2007). Thus, food craving refers to an intense desire or urge to eat specific foods (Meule et al., 2014). The FCQs contain several self-report scales measuring food cravings on a multidimensional level, by covering behavioral, cognitive, and physiological aspects. The FCQs include two versions measuring current cravings (state version; FCQ-S) and habitual cravings (trait version; FCQ-T). The FCQ-S consists of 15 items to be scored on a 5-point scale (from "strongly disagree" to "strongly agree"), and the FCQ-T includes 39 items, scored on a 6-point scale (from "never" to "always"). In both versions, the participant is asked to fill the questionnaires with one specific food item in mind. The instruction given is to "think of (generally or momentary) craved food(s), while completing the scales". The FCQs have an excellent internal reliability overall, but the FCQ–T has higher test–retest reliability than the FCQ–S (Meule, 2020). This is because the FCQ-S is more sensitive to situational changes, such as food deprivation and food intake.

A few modified versions of the original FCQs were developed to serve experimental needs. A reduced version of the FCQ-T was validated with only 15 items (FCQ-T-r; Meule et al., 2014). Nijs et al. (2007) also modified the original FCQs to construct an index of general food craving instead of specific food cravings. To investigate the general experience of food craving, they developed the Trait and State General Food Cravings Questionnaires (G-FCQ-T and G-FCQ-S; Nijs et al., 2007) where the participant does not focus on a specific food item while completing the scales. A Food Chocolate-Craving Questionnaire Trait (FCCQ-T) was also created to specifically assess chocolate cravings (Rodriguez et al., 2007). For a detailed presentation of these versions and their psychometric properties, we recommend the review recently published by Meule (2020).

The FCQs are thus useful and reliable instruments for assessing food cravings. In ERP research on food-related cognition, the FCQs can be used to assess whether particular brain activity in participants may underlie craving for certain foods. For example, Asmaro and colleagues used the FCCQ-T to compare the neurophysiological activity of chocolate cravers and non-cravers when processing chocolate pictures (Asmaro et al., 2012). In cravers, chocolate pictures selectively enhanced an early frontal positivity that was not modulated by satiety. In addition, the LPP amplitude was larger for chocolate than for other food pictures in both chocolate cravers and non-cravers. The authors concluded that an early frontal positivity may index unrestrained wanting of chocolate in cravers only.

The FCQs can also be used in combination with other questionnaires to test for possible interactions between different aspects of eating behavior on cerebral activity. For example, Blechert et al. (2014) tested whether emotional state influenced food cravings differently in high and low emotional eaters. They used the FCQ-T to assess food cravings, and the emotionality scale of the Dutch Eating Behavior Questionnaire (presented in the next section) to create groups of high and low emotional eaters. They reported that since emotional eating and FCQ-T presented high collinearity, trait food craving may have contributed to the larger LPP amplitudes observed in high emotional eaters when viewing pictures of high-caloric food.

Finally, there is evidence that FCQ-T scores are associated with obesity and certain eating disorders, such as anorexia nervosa and binge eating disorder (Meule, 2020). In particular, individuals with high FCQ-T scores show a stronger approach tendency towards high-calorie food cues (Brockmeyer et al., 2015) and present stronger reward-related brain activations in response to high versus low-calorie food cues (Ulrich et al., 2016). These processes may contribute to the inability to resist food intake. Future ERP research should thus pursue the evaluation of the link between food cravings, cognitive functioning and dysfunctional eating behavior, in order to better understand the mechanisms underlying eating disorders. For example, an interesting avenue of research could be to explore the link between food cravings and reward processing in individuals with different eating disorders, with the measure of reward-related components such as the RewP (Proudfit, 2015).

– *Dutch Eating Behavior Questionnaire* (DEBQ; Van Strien et al., 1986)

The DEBQ is a self-report questionnaire with 33 items, measuring three aspects of eating behavior: emotional eating (13 items), external eating (10 items), and restrained eating (10 items). Emotional eating refers to the propensity to eat in response to emotions (example item: "do you have a desire to eat when you are feeling lonely?"). External eating refers to an increased tendency to eat in response to external cues, such as food odors (example item: "if the food tastes good to you, do you eat more than usual?"). Restrained eating refers to the intention to limit food intake, with the goal of losing weight or preventing weight gain (example item: "if you have put on weight, do you eat less than you usually do?"). Answers to the items range from 1 (never) to 5 (very often), with higher scores indicating greater endorsement of the eating behavior. All DEBQ scales have high internal consistency and factorial validity (Barrada et al., 2016; Van Strien et al., 1986), making them reliable tools for measuring eating behavior.

The DEBQ thus provides a quick measure of three important aspects of eating behavior that can have a major influence on our food choices and the amount of food that we eat. Indeed, both emotional and external eating have been identified as vulnerability factors for overeating (Brownley et al., 2016; Hou et al., 2011), and external eating has been found to be the main predictor of food craving (Burton et al., 2007). In addition, a direct relationship was shown between the scores of the restraint scale of the DEBQ and successful caloric restriction in everyday life (Laessle et al., 1989). These results support the value of this scale to gain insight into the actual dieting behavior of individuals.

In the literature on food-related cognition, the DEBQ is used to assess the brain activity of individuals based on their propensity to be emotional eaters, external eaters, or restrained eaters. For example, Carbine and colleagues used the DEBQ to investigate the link between emotional and external eating and inhibitory control toward food cues (Carbine, Christensen, et al., 2017). As an index of inhibitory control, they measured the N200 peak elicited in response to low and high-calorie food pictures in a Go/No-Go task (see section 2.3. for more details on this study). However, the results showed no significant correlations between N200 amplitude and the scores to both scales. In other ERP studies, the DEBQ was also used to divide participants into groups of restrained and unrestrained eaters (Kong et al., 2015), or low and high emotional eaters (Blechert, Goltsche, et al., 2014).

In our view, future ERP research should focus on assessing whether different eating behaviors (as measured by DEBQ scales) are associated with automatic detection and privileged processing of certain foods in the environment. Indeed, we live in an environment that is considered increasingly obesogenic, with food cues constantly present through advertising. Such a setting is likely to cause overeating in some individuals, particularly those with high externality scores (Burton et al., 2007). Emotions evoked by food stimuli could also influence eating behaviors (for a review of methods for measuring food-evoked emotions, see Kaneko et al., 2018). For example, food-evoked emotions could modulate the perceptual and cognitive processing of certain food cues, and encourage some eating behaviors such as emotional eating. In conclusion, a better understanding of the brain and cognitive mechanisms that may influence the response to environmental triggers would help prevent and possibly reduce unhealthy eating behaviors.

– *Three-Factor Eating Questionnaire* (TFEQ*;* Stunkard & Messick, 1985)

The TFEQ is a 51-item self-report questionnaire, designed to measure three dimensions of eating behavior: cognitive restraint (21 items), disinhibition (16 items), and hunger (14 items). Cognitive restraint refers to the conscious restriction of food intake for the purpose of weight control or weight loss (example item: "How likely are you to shop for low-calorie foods?"). Disinhibition refers to a periodic loss of control over eating, in the form of increased frequency and/or volume of food intake (example item: "Do you go on eating binges though you are not hungry?"). Hunger measures whether appetite drives food intake, and the extent to which the person engages in emotional eating (example item: "How frequently do you skip dessert because you are no longer hungry?"). The TFEQ has a good internal consistency, with high test–retest reliability (Stunkard & Messick, 1985).

A few revised and shorter versions of the original TFEQ were developed based on psychometric analyses. One of the most used is the Three-Factor Eating Questionnaire–R18 (TFEQ-R18; Karlsson et al., 2000). The TFEQ-R18 consists of 18 items that assess three factors: cognitive restraint (6 items), uncontrolled eating (9 items), and emotional eating (3 items). The "cognitive restraint" factor assesses the same behaviors as the factor with the same name in the original TFEQ, but the two other factors have a different meaning. The "uncontrolled eating" dimension actually combines the disinhibition and the hunger factor from the original TFEQ, as it refers to the propensity to eat more than usual due to a loss of control over eating along with a subjective sensation of hunger. Finally, emotional eating refers to the inability to resist emotional cues. Several studies examined the construct validity of the TFEQ-R18 in different populations, and the results showed that the TFEQ-R18 had adequate psychometric properties for measuring three dimensions of eating behavior (Anglé et al., 2009; Martins et al., 2021).

In addition, direct relationships have been found between TFEQ-R18 scores and reported food intake in different populations. For example, a study showed that consumption of high-calorie foods was positively associated with uncontrolled eating, and that girls with high scores on cognitive restraint had lower energy intake than other girls (Lauzon et al., 2004). This study also showed that people scoring high on emotional eating snack more than others between meals. In parallel, a significant negative correlation was reported between caloric intake and the restraint scores from the original TFEQ in individuals with eating disorders (Zambrowicz et al., 2019). The TFEQ restraint scale is thus a useful measure of dietary restriction, but a relationship between food intake and the other scales of the original TFEQ is less clear (James et al., 2017). The TFEQ-R18 could be more effective in distinguishing among different eating patterns.

In the literature on ERPs and food-related cognition, a few studies used the TFEQ to detect group differences in eating behaviors. For example, Hachl and colleagues used the cognitive restraint scale of the TFEQ to create groups of restrained and unrestrained eaters (Hachl et al., 2003). The study investigated the effects of restrained eating and food intake on ERPs elicited by the presentation of food-related and food-unrelated words. They observed that eating a snack led to a reduction in P200 amplitude in restrained eaters, and an increase in unrestrained eaters. This suggests that food intake influences the motivational value of stimuli differently between restricted and unrestricted eaters. The TEFQ was also used as a supplementary assessment in a few other ERP studies (Hume et al., 2015; Kong et al., 2015; Kumar et al., 2016).

The TFEQ and its revised versions can therefore be used in combination with ERP measures to study the relationship between different eating behaviors and attention to environmental food cues. In addition to attentional processes, other brain functions would benefit from being studied in relation to TFEQ scores (e.g. sensory processing, inhibition, memory, decision taking). However, some eating behaviors measured by the TFEQ and the TFEQ-R18 are similar to those measured by other scales, such as restraint eating and emotional eating, which are also found in the DEBQ. Future ERP research should focus on measures specific to the TFEQ that are less studied, such as disinhibition or uncontrolled eating. High scores on these dimensions may be associated with deficits in cognitive control and may influence food choices, both of which can be assessed via ERPs. For example, a link between uncontrolled eating and inhibitory function could be tested with the N200 peak, whose amplitude could vary according to the type of food stimuli (e.g. sweet vs. savory foods). Other factors, such as cravings, could also moderate the relationship between these parameters. Once again, we encourage the study of the interaction between several eating behaviors to better understand food decision making, which is determined by multiple factors.

– *Restraint Scale* (Polivy et al., 1978)

The Restraint Scale is one of the most used measures for the assessment of dietary restraint. Dietary restraint refers to a restrictive eating style, with the intent to achieve or maintain a desired weight. Thus, it is a useful tool for the identification of chronic dieters (Heatherton et al., 1988). The Restraint Scale consists of 10 items assessing weight fluctuation and subjective concern for dieting. Some data suggest that the Restraint Scale has an adequate internal consistency (Heatherton et al., 1988). However, it seems that the scale has a lower reliability in obese individuals, compared with normal-weight individuals (Ruderman, 1983). The factorial structure of the Restraint Scale seems also inconsistent between obese and normal-weight subjects, suggesting that some of the items may have a different meaning in the two populations (Ruderman, 1983). In addition, this scale may overestimate restraint in overweight people (van Strien et al., 2007). The Restraint Scale thus appears to have reasonable psychometric properties for assessing dieting and weight concerns in the normal-weight population, but it may be less reliable in overweight and obese individuals.

Several questionnaires offer an assessment of restrained eating, but they do not measure exactly the same aspects of this eating behavior. For example, one study attempted to demonstrate the relationship between scores on restrained eating scales and the self-reported mean caloric intake (Laessle et al., 1989). Three questionnaires were compared: the Restraint Scale, the restraint factor of the TFEQ, and the restraint factor of the DEBQ. High scores on the Restraint Scale were related to consequences of unsuccessful dieting, such as weight fluctuations, but no to successful caloric restriction. In constrast, high scores on the restraint factors from the TFEQ and the DEBQ were associated with successful dieting. Thus, these questionnaires do not measure exactly the same components of restrained eating. The choice of which restraint scale to use must therefore be carefully determined according to the hypotheses being tested.

In the literature on ERPs and food-related cognition, a few studies used the Restraint Scale either as a control measure (Becker et al., 2016), or to create groups to compare (Blechert et al., 2010). For example, Blechert et al. (2010) wanted to determine the conditions under which restrained eaters may show enhanced or reduced reactivity to high-calorie food cues. They used the Restraint Scale to compare the LPP component elicited by food pictures in restrained and unrestrained eaters. The LPP was measured as an index of the motivational salience of food stimuli. In one condition, the participants were told that the foods presented will be available for consumption after the task (vs. a control condition). The results showed a reduced LPP amplitude for available foods in restrained eaters only. This modulation of the LPP by food availability suggests a down-regulation of the salience of the available food cues in restrained eaters.

In summary, the Restraint Scale is useful for comparing the brain activity of individuals according to their subjective concern for dieting and weight fluctuation. However, the Restraint Scale scores are not directly related to successful caloric restriction. Researchers interested in comparing successful and unsuccessful restrained eaters will need to conduct additional assessments. In this context, an important parameter of influence on successful caloric restriction could be the emotional state. Indeed, it has been shown that a negative mood is an important trigger for overeating in restrained eaters (Bian et al., 2021). Future ERP studies on the influence of emotions on food-related cognition in restrained and unrestrained eaters would provide a better understanding of the mechanisms underlying successful dieting. Another line of research could focus on cognitive flexibility, a facet of executive functioning less often studied than inhibition, which can be assessed via the N200 component. This function allows individuals to adapt their behaviors to the environment, and could be altered in unsuccessful restrained eaters (Han et al., 2021).

3.4.2. Questionnaires assessing eating disorder symptoms

In the literature on food-related cognition, eating disorder symptoms are assessed either through an interview or via standardized questionnaires. We will present below two of the most commonly used questionnaires to examine the presence of eating disorder symptoms: the Eating Attitudes Test and the Eating Disorder Examination Questionnaire.

– *Eating Attitudes Test* (EAT-26; Garner et al., 1982)

The EAT-26 is a self-report questionnaire that assesses symptoms and concerns characteristic of eating disorders. It includes 26 items divided in three subscales measuring dieting (pathological avoidance of fattening foods and concerns about body image), bulimia and food preoccupation, and oral control (self-control about food intake). Each item is rated on a six-point scale ranging from “always” to “never”, based on how frequently the individual engages in specific behaviors. Individuals who score higher than 20 are advised to seek further evaluation from a qualified professional. The EAT-26 is actually a revised version of the original EAT-40 that included 40 items. By using factor analysis, the EAT-40 was abbreviated by eliminating redundant items ($n = 14$) that did not increase the predictive power of the scale (Garner et al., 1982). The EAT-26 has good psychometric properties of reliability and validity (Garfinkel & Newman, 2001; Garner et al., 1982).

The EAT-26 was designed as a screening tool to identify eating disturbances in at-risk and non-clinical populations. However, it has a low predictive value for specific eating disorders such as anorexia nervosa or bulimia nervosa (Garfinkel & Newman, 2001; Garner et al., 1982). This is because eating disorders exist on a continuum and that other parameters (such as denial and social desirability) can affect the answers to self-report questionnaires (Garfinkel & Newman, 2001). Thus, the EAT-26 does not provide a diagnosis for specific eating disorders, but it can be used as the first part of a 2-part diagnostic screen, the second part involving a clinical interview with a professional. It is nevertheless useful for detecting risky eating behaviors in both clinical and non-clinical populations, or for assessing the severity of eating disorder symptoms in clinical populations and their evolution over time.

In the current literature on ERPs and food-related cognition, the EAT-26 has been mostly used for controlling the absence of symptoms characteristics of eating disorders in the participants (Asmaro et al., 2012; Leland & Pineda, 2006). It was also used by Edwards et al. (2018) to investigate the cerebral correlates of eating disturbances and cognitive flexibility among overweight and obese adults. Cognitive flexibility was assessed by measuring the P300 component in a task-switching paradigm. The results showed that only scores on the “bulimia and food preoccupation” subscale were related to longer P300 latencies, but independently from weight status. However, no significant relationships were observed between this subscale and reaction times, suggesting that other neurophysiological mechanisms may influence cognitive flexibility. Further research is needed to better understand the influence of eating disturbances, as measured by the EAT-26 subscales, on cognitive function.

In summary, the EAT-26 is useful to compare the brain activity of different populations based on the eating behaviors at risk for developping an eating disorder (e.g. normal-weight vs. overweight individuals, male vs. female). More research on food-related cognition in clinical populations is also needed to better understand how individuals perceive and process food cues in relation to their eating disturbances, with the goal of treating the symptoms. For example, there is evidence that patients suffering from anorexia nervosa present a decreased attentional engagement with food cues, which could contribute to successful control of food intake (Jonker et al., 2019). The EAT-26 would enable us to assess whether there is a specific behavior associated with this reduction in attention, by comparing the relationship between the scores obtained on the three subscales ("dieting", "bulimia and food preoccupation", and "oral control") and brain activity. Each score could be associated with a different effect on cognitive function and subsequent behavior. This would then allow for a more targeted intervention on a given behavior to reduce symptoms. Future studies could also investigate parameters that may influence attention to food in anorexic patients, such as hunger, type of food, or emotional state. Of course, such an approach should be applied to the study of other eating disorders such as bulimia nervosa or binge eating, and other cognitive functions would benefit from being studied (e.g. cognitive flexibility, inhibition).

- *Eating Disorder Examination Questionnaire* (EDE-Q; Fairburn & Beglin, 1994)

The EDE-Q is a self-report questionnaire measuring eating disorder symptoms. It is based upon the Eating Disorder Examination, which is an investigator-based interview (Fairburn & Beglin, 1994). It was designed to be completed more easily and quickly (i.e. in less than 15 min) than the Eating Disorder Examination interview. The current version (EDE-Q 6.0) includes 28 items assessing the cognitive and behavioral features of eating disorders through four subscales: restraint, eating concern, shape concern, and weight concern. The participant is instructed to answer based on the past four weeks, by using a 7-point forced-choice rating scheme. A score can be calculated for each subscale by adding the ratings of the relevant items and dividing the sum by the total number of items forming the subscale. A global score can also be calculated by summing up the four subscales scores and dividing the total by four. Higher scores denote more problematic eating behaviors and attitudes. The EDE-Q has good internal consistency overall, and current data provide support for its reliability and validity for assessing eating disorder symptoms (Berg et al., 2012).

Thus, the EDE-Q is a useful tool for measuring the intensity of various eating disorder symptoms in clinical and non-clinical populations. To our knowledge, this questionnaire has been little used in research on ERPs and food-related cognition. An example comes from Blechert et al. (2011), who investigated the ERPs elicited by food pictures in participants with anorexia nervosa, bulimia nervosa, and healthy controls. They used the EDE-Q to obtain descriptive information regarding eating disorder symptomatology in the participants, but did not test any specific hypothesis regarding the influence of these scores on brain activity. Outside of research on food-related cognition, one study showed that higher EDE-Q scores were associated with enhanced P300 amplitude during local visual processing, suggesting that eating disorders symptoms are associated with differences in local and global visual processing (Moynihan et al., 2016). This study involved abstract stimuli, but we can wonder whether food stimuli would modulate brain activity differently depending on the symptoms presented by the participants.

Further research should investigate the relationship between EDE-Q scores and the brain processes underlying food-related cognition. The symptoms measured by the 4 subscales could have a different impact on brain activity, depending on the populations tested. As previously discussed in the section on the EAT-26, we wish to encourage ERP research on food-related cognition in populations with eating disorders, as specific brain and cognitive processes could explain some symptoms. In addition, we would like to point out that the scores obtained via the EDE-Q and the EAT-26 do not provide exactly the same information about eating disorder symptoms. For example, the "dieting" scale of the EAT-26 combines aspects related to restrained eating and concerns about body image and shape, whereas these aspects are measured by two different scales in the EDE-Q ("restraint" and "shape concern"). This fact should be taken into account when selecting one of these questionnaires to test a particular hypothesis. It may also be interesting to combine several questionnaires in order to have a more complete view of the many parameters that may influence pathological eating behaviors.

4. Stimuli

In this section, we will review the stimuli that have been used to elicit ERPs in research on the cerebral processing of food information. Food cues are multimodal by nature and can be processed by several sensory modalities such as sight, smell, or taste. The most common stimuli in the literature on ERPs and food-related cognition are pictures, followed by words. Only a few studies used taste and olfactory stimuli. We will present and discuss the different stimuli used, the experimental conditions that were compared (e.g. food vs. non-food stimuli), the relevance of a "non-food" category, and a few perspectives for future research.

4.1. *Type of stimuli*

4.1.1. *Pictures*

In the literature on ERPs and food-related cognition, pictures are the most used stimuli. Through studies, we observed a variety of different picture contents such as edible vs. non-edible foods (Becker et al., 2016); high-calorie vs. low-calorie foods (Meule et al., 2013); different types of food compared with each other (e.g. meat vs. vegetables; Schwab et al., 2017; Stockburger, Renner, et al., 2009); or food vs. non-food items (e.g. emotional and erotic scenes, flowers, rocks, office supplies; Blechert et al., 2010; Carbine, Larson, et al., 2017; Gable & Harmon-jones, 2010; Hanlon et al., 2012; Nijs et al., 2008; Stockburger et al., 2008; Stockburger, Schmälzle, et al., 2009; Versace et al., 2015). For example, Becker et al. (2016) investigated the differences in the ERPs elicited by edible and non-edible food pictures with a passive viewing task. They reported larger P100 and N100 amplitudes to inedible than edible foods, suggesting that food cues that represent a greater health risk capture greater attention at very early stages of cerebral processing.

Food pictures were mainly selected from the Foodpics database (https://www.food-pics.sbg.ac.at; Meule et al., 2013; Schwab et al., 2017), existing cookbooks (Stockburger et al., 2008), or on internet (Blechert et al., 2010). Some authors also created their own database to answer specific experimental needs (Becker et al., 2016). Non-food pictures seemed to be mainly selected from the International Affective Picture System (IAPS; Lang et al., 2008) or on internet (Blechert et al., 2010; Stockburger et al., 2008; Versace et al., 2015). However, we noticed that the source of the stimuli is not always indicated. Providing the source of the stimuli, or at least giving a few examples of the stimuli used, is necessary to promote the reproducibility of the study.

There are several criteria to control to avoid potential bias when using pictures as stimuli. In particular, the pictures need to be homogeneous in terms of visual parameters, in order to prevent some pictures from capturing more attention than others due to perceptual differences. The important visual parameters to control include complexity (number of food items displayed in one picture), brightness, contrast, object size, viewing distance, and background color. Pictures also need to be identical in size and resolution, which can be easily done with any image editing software. Brightness, contrast, and object size are often provided by standardized picture databases, such as in the FoodPics database (Blechert, Meule, et al., 2014). If picture properties are not available, they can be calculated. Some Matlab scripts can be found online in this purpose, but to our knowledge, there is unfortunately no ready-to-use or automated method to calculate these parameters.

Apart from perceptual parameters, subjective parameters such as the palatability and familiarity of the foods depicted in the pictures may also be important to control, especially for studies involving the comparison of different food categories. The FoodPics database also provides data regarding palatability and familarity for each picture, but the pictures were rated by volunteers from German-speaking and North American countries. As culinary habits differ across cultures, these ratings may not directly apply to all cultures (Blechert, Meule, et al., 2014). Thus, when selecting pictures from this or other databases, a pilot study seems necessary to validate the picture selection in terms of subjective parameters such as palatability or familiarity.

4.1.2. Words

Besides pictures, other types of food-related stimuli have been used but to a much lesser extent, including words, taste stimuli, and olfactory stimuli. Words have been used in different tasks to investigate food-related cognitive functions, such as modified Stroop tasks (Nijs, Franken, et al., 2010), identification tasks (Hachl et al., 2003; Leland & Pineda, 2006; Plihal et al., 2001), memory tasks (Pietrowsky et al., 1994), or lexical decision tasks (Benau & Moelter, 2016). ERPs have been measured for words depicting various foods (e.g. savory foods, sweet foods, high and low-calorie foods, palatable foods), and compared with the ERPs elicited by various non-food words (e.g. erotic words, nature words, words depicting everyday objects, office and art supplies). For example, Benau & Moelter (2016) investigated the influence of the content of lexical stimuli and physiological state (hunger, thirst, wakefulness) on response monitoring. They measured several ERP components while the participants made orthography judgments in a lexical decision task including food and non-food words and pseudowords (nonexistent but pronounceable words; e.g. "chease"). The participants were instructed to press one button if the presented word was spelled correctly, and another button if it was spelled incorrectly. One of the ERP components analyzed was the *error-related negativity* (ERN), which is elicited after the commission of a response, and associated with motivation and emotion. The results showed that ERN amplitude was significantly larger for errors to food words compared with non-food words, suggesting an increased sensitivity to errors involving food stimuli (Benau & Moelter, 2016).

Words are easy to use as food-related stimuli because there are many available options and few parameters to control. To avoid potential bias, the words need to be homogeneous regarding length (number of letters and syllables) and frequency of use. The few visual parameters to control include font, size, letter color, and background color. Similarly to picture stimuli, subjective parameters such as palatability and familiarity of the foods depicted by the words may also need to be controlled. As symbolic stimuli, however, words have a disadvantage: they do not hold the same potential to elicit arousal reactions as pictorial stimuli (e.g. pictures, facial expressions; Bayer & Schacht, 2014). The lower arousal level of words would then result in weaker physiological responses (Bayer et al., 2011; Houwer & Hermans, 1994). There is also evidence that words may elicit less emotions compared with pictorial stimuli, although this finding is not consensual in the ERP literature (for a review, see Bayer & Schacht, 2014). To our knowledge, there are no studies directly comparing the arousal level, the physiological responses, and the ERPs elicited by food words and food pictures. It is therefore difficult to assert that food words are less arousing and would elicit weaker responses than food pictures. This would be an interesting research topic to explore in the context of food marketing. Indeed, words and pictures of food are widely used in advertising, and they could have a different impact on the food choices of individuals.

4.1.3. Tastes

A few studies included taste stimuli to investigate the ERPs associated with food-related cognition (Franken et al., 2011; Schienle et al., 2017; Schwab et al., 2017; Viemose et al., 2013). In particular, taste stimuli have been used in taste conditioning tasks to examine the neural correlates of appetitive conditioning (Franken et al., 2011; Viemose et al., 2013). Taste stimuli are also relevant to induce a particular state. For example, a bitter drink was used in two studies to induce disgust in female participants, before recording ERPs while they watched food pictures (Schienle et al., 2017; Schwab et al., 2017). The results showed overall that the perception of a bitter taste reduced the P200 and LPP to food pictures in healthy women, but increased the LPP in women with binge-eating symptoms. This phenomenon may reflect an alteration of cross-modal integration in patients with binge-eating symptoms, which may contribute to overeating (Schienle et al., 2017).

Thus, the influence of taste stimuli on neural activity has been mostly studied in interaction with food pictures. The interaction between taste and other food stimuli would constitute a relevant avenue of research for future ERP studies. In particular, the combination of odor and taste stimuli is interesting to study because it creates flavor, which influences the reward value of food in the orbitofrontal cortex (Rolls, 2015). Moreover, an important property of odor–taste interactions is that an odor can actually enhance a taste, a phenomenon called odor-induced taste enhancement (OITE). In this line of research, Sinding et al. (2021) recently measured olfactory-gustatory ERPs to study the cerebral mechanisms of odor-induced saltiness enhancement (OISE). From a green-pea soup base, they created five solutions with different salt and aroma quantities to produce OISE (a beef stock aroma was chosen because of its ability to increase saltiness). The solutions were delivered directly into the mouth of the subjects with a gustometer, while the EEG was recorded. The results showed that the P300 peak was delayed during OISE, but not the P100 peak. As only the late cognitive P300 peak was modulated by OISE, the authors concluded that odor–taste interaction may happen in high-level integration areas (Sinding et al., 2021). These innovative results should encourage further research in this field.

Finally, several parameters need to be controlled when selecting taste stimuli for an experimental study, such as taste intensity, recognizability, familiarity, and palatability. These parameters can be assessed in a pilot study prior to the main study, by directly asking the participants to rate the stimuli. Ageusia (i.e. loss or impairment of the sense of taste), although very rare, should be defined as a non-inclusion criterion when recruiting participants. To ensure that all participants have a normal taste function, their taste abilities can also be controlled with a gustatory identification test (e.g. Burghart Taste Strips; Landis et al., 2009). In ERP studies involving taste stimuli, recording the electromyogram from facial muscles could also help to control for artifacts created by chewing movements.

4.1.4. Odors

To our knowledge, only a couple of ERP studies on food-related cognition used olfactory stimuli as food cues (Wolz et al., 2017; Zsoldos et al., 2021). For example, Wolz et al. (2017) investigated the influence of chocolate and neutral odors on the ERPs elicited by chocolate and neutral pictures, in patients with binge-eating disorders and healthy controls. The odor of a pencil was defined as the neutral odor, and the neutral pictures depicted office items. The authors expected binge-eating patients to have more motivated attention (LPP) and less cognitive control (N200) than healthy subjects, in presence of chocolate-related stimuli. The results showed that N200 amplitude was larger in patients for chocolate pictures primed by a chocolate odor, compared with a neutral odor. No such effect was observed in the control subjects. These results support the hypothesis of an additive effect of olfactory and visual chocolate stimuli, but in binge-eating patients only.

Food odors are particularly interesting to study because they have an important influence on food choice behaviors. There is indeed evidence that the presence of food odors in the environment increases appetite for the congruent products, especially if the odors are non-attentively perceived (Chambaron et al., 2015; Gaillet et al., 2013, 2014; Zoon et al., 2016). For example, Gaillet et al. (2013, 2014) showed that the presence of a fruity odor (e.g. pear, melon) at a very low intensity increased the choice of vegetable-based plates and fruits from a buffet, compared with a non-odorized condition. We recently used a similar olfactory priming paradigm to examine the influence of non-attentively perceived food odors on the ERPs elicited by food pictures, in normal-weight, overweight, and obese adults (Zsoldos et al., 2021). We selected a pear and a pound cake odor as primes, respectively priming sweet low-energy–density foods and high-energy–density foods. EEG was recorded while the participants passively watched pictures of sweet low and high-energy–density foods, under the two priming conditions plus an odorless control condition. The P100, N100, P200, and N400 were analyzed. We observed that overweight and obese subjects presented larger P200 amplitudes to low-energy–density food pictures in presence of both odors, a phenomenon also observed in the odorless condition for overweight subjects only. Overweight and obese individuals might thus differ in the automatic engagement of attentional resources toward food pictures in the absence of food odors. The impact of these neurophysiological differences on food choices remains to be tested.

Finally, several parameters need to be controlled when using odors as stimuli, such as intensity, recognizability, palatability and familiarity of the odors. As with taste stimuli, all these parameters can easily be assessed in a pilot study. Anosmia (i.e. the partial or total loss of the sense of smell) should be defined as a non-inclusion criterion when recruiting the participants. To ensure that all participants are normosmic, their olfactory abilities can be assessed with standardized tests such as the Sniffin' Sticks test (Burghart, Wedel, Germany; Hummel et al., 2007) or the European Test of Olfactory Capabilities (ETOC; Thomas-Danguin et al., 2003). The experiments involving olfactory stimuli should also take place in a well-ventilated room or a positive pressure room to avoid residual odors during the recording sessions.

4.2. Experimental conditions

All the articles reviewed in the literature on ERPs and food-related cognition included food-related stimuli, but the experimental conditions compared varied a lot across studies. We can group them into two main categories: the studies comparing different categories of food stimuli (e.g. sweet vs. savory foods), and the studies comparing food stimuli to non-food stimuli (e.g. palatable foods vs. office items). The studies comparing food to non-food stimuli are more frequent, but the variability of the non-food stimuli used is very high across studies (e.g. emotional pictures, erotic pictures, sceneries, various manufactured objects).

The inclusion of a non-food category is relevant to investigate the differences in the cerebral processing of food and non-food stimuli in various populations. However, further ERP research comparing different types of foods (e.g. high vs. low-calorie foods) is needed, because it is more representative of what happens in everyday life when we chose what to eat (Carbine et al., 2018). Indeed, increased cerebral processing of specific food cues may influence attention orientation toward these foods, and thus impact the subsequent food choices. The ERPs elicited by different food cues may also be modulated by other parameters such as weight status, eating habits, or the presence of eating disorders. In general, new paradigms should be developed to provide a better simulation of real-life situations involving food choices (e.g. supermarket, restaurant), in order to better understand food decision making.

The food categories that can be compared are endless (e.g. low vs. high-energy foods, fruits vs. vegetables, sweet vs. salty foods). However, it is important to clearly define these categories beforehand. For example, the distinction between healthy and unhealthy foods may be difficult for participants to make. More theoretical knowledge is needed to objectively assess the health impact of different foods. A categorization of stimuli based on the energy value of foods (low vs. high-energy) seems actually more common than a categorization based on healthiness. Roughly quantifying calories may be easier and less subjective than assessing the impact on health. Moreover, this categorization seems to occur very early, as differences in brain processing depending on energy value were observed as early as 100 ms (Zsoldos et al., 2021). Categorization errors are however possible when foods are ambiguous. For example, it is common to think that fruit juices are low in calories, when in fact they can be high-energy. We thus recommend carefully selecting the most representative stimuli for each category of interest, and avoiding ambiguous stimuli.

Finally, we noted that the non-food stimuli category is frequently referred to as the "neutral condition". The terms "neutral stimuli" make sense in studies using emotional stimuli, because they refer to the stimuli that do not elicit any emotion. However, there is no actual "neutral condition" in comparison to food stimuli, as "neutral foods" may not exist. To our knowledge, one study attempted to put together a proper "neutral food" category, by selecting food pictures depicting bland and uncooked foods with little taste (e.g. pasta, rice, various beans; Asmaro et al., 2012). Studying the parameters that may qualify a food as "neutral" may constitute an interesting line of research, especially as they may vary across countries and cultures.

4.3. Stimuli: Summary and perspectives

In summary, we reported that pictures are the most used stimuli in the literature on ERPs and food-related cognition, followed by words, taste stimuli, and odor stimuli. Vision is usually considered the most important sense in humans, which can explain the popularity of visual stimuli like pictures and words (Hutmacher, 2019). Food pictures and food words are also easier to find in standardized databases or the internet, and they are easier to manipulate than taste or odor stimuli. In particular, the presentation parameters are easier to control for visual stimuli during experimental sessions (i.e. apparition time, length of presentation, end of presentation), which is slightly more complex with taste or odor stimuli. Depending on the topic and the design of the study, a specialized instrument can be necessary to deliver taste and/or odor stimuli (e.g. gustometer, olfactometer). The same ERP components can be measured for the different sensory modalities, although peak latencies may differ across experimental designs. . In general, more ERP studies including taste or odor stimuli are necessary to obtain valuable information on the processing of food cues.

Because food is naturally multimodal, future research should further explore the brain processing of food cues involving multiple sensory modalities at once. Such research could bring some light on the neurophysiological markers of eating disorders such as binge eating, which has already been associated with altered cross-modal integration of food cues (i.e. tastes and pictures; Schienle et al., 2017). For example, it is possible to combine visual stimuli with odor or taste stimuli, or odor and taste stimuli. To our knowledge, most studies combining sensory modalities actually measured visual ERPs elicited by food pictures in the presence of a sustained stimulation from another sensory modality (tastes or odors; Schienle et al., 2017; Zsoldos et al., 2021). This technique is useful for assessing whether visual ERPs are modulated by the stimulation of another sense, but it does not really measure bimodal ERPs. To measure multimodal ERPs resulting from the combined processing of several sensory information, the main difficulty lies in synchronizing the stimuli so that they are perceived at exactly the same time by the subjects. This can be challenging because of the different temporal resolutions of each sense, but it is possible with appropriate devices like the olfactometer and the gustometer. For example, the olfactometer has a temporal resolution of about 10 ms, which allows the delivery of odorous molecules with a sufficiently strong flow so that they arrive rapidly on the olfactory mucosa. The stimulation parameters (e.g. presentation duration of the stimuli, interstimulus interval) must also be carefully determined according to the different temporal resolutions. For example, the interstimulus interval can be shorter for visual stimuli (<1 s) than for odor or taste stimuli (15–30 s; Boesveldt et al., 2007; Schriever et al., 2017). This interval is necessary to allow full recovery of the olfactory or gustatory function for the next stimulation. This also implies that more repetitions can be made with visual stimuli than with other types of stimuli for the same session duration.

In summary, we think that new paradigms should be developed to be closer to real-life situations where individuals are confronted with food cues. A higher variety of food cues from different sensory modalities is needed to better understand the brain mechanisms underlying food perception and food choices. Because food is multimodal, future research should also explore the brain processing of food cues involving multiple sensory modalities. Using real foods as stimuli could be an option. Finally, future studies should focus on comparing the cerebral activity elicited by different categories of foods (e.g. low-calorie vs. high-calorie foods), instead of comparing foods to non-food objects.

5. General conclusion

The development of a new study always starts with a review of the literature, including both theoretical and methodological aspects. By writing the current narrative review, our objective was to provide an overview of methods for all researchers intending to study the ERPs associated with food-related cognition. We focused on basic methodological choices, such as task or stimuli selection, and tried to raise some important questions to ask when developing an ERP study in the context of food science. Of course, there are many other methodological parameters to take into consideration when doing ERP research that are not specific to the study of food-related cognition (e.g. EEG recording, ERP data processing, statistical analysis). These aspects are beyond the scope of this article, but for a more in-depth discussion on ERP analysis, we recommend the reference book by Luck (2014). In our opinion, following the good practices highlighted throughout this paper is necessary to reduce methodological bias and improve the reproducibility of the results. We hope that this work will inspire original and innovative research in the promising field of ERPs and food-related cognition.

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CRediT authorship contribution statement

Isabella Zsoldos: Conceptualization, Writing – original draft, Writing – review & editing, Visualization. **Charlotte Sinding:** Conceptualization, Supervision, Project administration. **Stéphanie Chambaron:** Conceptualization, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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