Food Research International 97 (2017) 199–208

Contents lists available at ScienceDirect

Food Research International

journal homepage: www.elsevier.com/locate/foodres

Visual attention to food cues is differentially modulated by gustatory-hedonic and post-ingestive attributes

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A R T I C L E I N F O

Keywords:
Antisaccade
Attentional bias
Food avoidance
Food related-cue
Food reward
Free viewing

A B S T R A C T

Although attentional biases towards food cues may play a critical role in food choices and eating behaviours, it remains largely unexplored which specific food attribute governs visual attentional deployment. The allocation of visual attention might be modulated by anticipatory postingestive consequences, from taste sensations derived from eating itself, or both. Therefore, in order to obtain a comprehensive understanding of the attentional mechanisms involved in the processing of food-related cues, we recorded the eye movements to five categories of well-standardised pictures: neutral non-food, high-calorie, good taste, distaste and dangerous food. In particular, forty-four healthy adults of both sexes were assessed with an antisaccade paradigm (which requires the generation of a voluntary saccade and the suppression of a reflex one) and a free viewing paradigm (which implies the free visual exploration of two images). The results showed that observers directed their initial fixations more often and faster on items with high survival relevance such as nutrient and possible dangers; although an increase in antisaccade error rates was only detected for high-calorie items. We also found longer prosaccade fixation duration and initial fixation duration bias score related to maintained attention towards high-calorie, good taste and danger categories; while shorter reaction times to correct an incorrect prosaccade related to less difficulties in inhibiting distasteful images. Altogether, these findings suggest that visual attention is differentially modulated by both the accepted and rejected food attributes, but also that normal-weight, non-eating disordered individuals exhibit enhanced approach to food's postingestive effects and avoidance of distasteful items (such as bitter vegetables or pungent products).

1. Introduction

Under strong survival pressure, organisms face the problem of identifying food sources, avoiding lethal toxins and eating a nutritionally balanced diet. In humans, this activity basically relies on vision when it comes to locate, identify and select potential food in the environment. While searching nutritious sources of food, visual scenes typically contain many objects that compete for the control of visual attention and eye movements, which cannot all be processed simultaneously because of our inherently limited information-processing resources. To overcome such limitations, the allocation of visual attention is determined by bottom-up factors like physical salience of the objects (e.g., its colour, orientation or velocity; Wolfe, 2007) and by top-down factors like incentive salience (constructed via its learned rewarding value given by the brain; Horstmann, 2015). The interaction of bottom-up sensory information and top-down influences creates an integrated saliency map of the visual environment that flags regions of interest in the retinal image; this map appears to be distributed across areas of the visual cortex and is closely linked to the oculomotor system that controls eye movements and orients the gaze to locations in the visual scene characterized by a high salience (Treue, 2003).

Among the visual stimuli with high incentive salience, food-related visual cues are particularly effective at grabbing attention. Indeed, viewing pictures of food as opposed to non-food appears to enhance attention in both normal-weight and overweight/obese individuals when measuring the activation of brain regions related to attention via functional magnetic resonance imaging (Yokum, Ng, & Stice, 2011) and event-related potentials (Nijs, Muris, Euser, & Franken, 2010). It is worth noting that food items differ in their properties such as taste-hedonic attribute (e.g., via the sensory pleasure of tasting non-caloric sweeteners) and nutritional value (e.g., calorie delivery), which both influence attention processing. For instance, using indirect methods for assessing attention to food-related visual stimuli, visual evoked potentials and response latencies during a spatial attention paradigm indicate that limited attentional resources are preferentially directed towards the processing of high-energy compared to low-energy food-related

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http://dx.doi.org/10.1016/j.foodres.2017.04.011
Received 13 December 2016; Received in revised form 8 April 2017; Accepted 10 April 2017
Available online 13 April 2017
0963-9969/

cues in weight loss maintainers and obese individuals (Harrar, Toepel, Murray, & Spence, 2011; Phelan et al., 2011; Toepel, Knebel, Hudry, le Coutre, & Murray, 2009). Considering the impact of the sensory-hedonic value, studies applying temporary devaluations in the pleasantness of the taste of high-energy foods via sensory-specific satiety and viewing the same as stimuli in a visual probe task revealed that the allocation of visual attention is rapidly adjusted to food images that are perceived to be more pleasant (di Pellegrino, Magarelli, & Mengarelli, 2011). However, spatial attention and visual probe paradigms only provide an simplified view of selective attention and tend to ignore relevant distinctions between the mechanisms involved in the initial orienting versus maintenance of attention as it is not possible to measure shifts in attention between stimuli presented side by side or gauge subject disengagement from pictures presented during the task (Doolan, Breslin, Hanna, & Gallagher, 2015).

More accurate and insightful measures for attention provided by direct and ecologically valid eye-tracking techniques also support the power of food pictures to capture visual attention in obese samples, eating-disorders patients and restrained eaters. In particular, an increased visual attention bias for high-energy foods (defined as the tendency to selectively attend to [orientation towards] and/or hold attention on [slowed disengagement from] high-energy food cues) have been revealed in those samples (Doolan et al., 2015; Kim, Kim, & Lee, 2016; Popien, Frayn, von Ranson, & Sears, 2015; Werthmann, Jansen, & Roefs, 2015; Werthmann et al., 2011, 2013). Surprisingly, preliminary evidence suggests that normal-weight, non-clinical and unrestrained individuals exhibit similar food-related attention biases. Thus, it could be assumed that biases consisting in selective attention towards high energy food are shared by everyone (Werthmann et al., 2015). Nevertheless, studies in subjects with normal eating and weight regulation habits remain scarce. In addition, available evidence is contradictive and generalization is limited, as so far only women were enrolled. For instance, Castellanos et al. (2009) and Nijs et al. (2010) reported enhanced initial gaze direction and gaze duration to the high caloric food pictures in normal-weight females, especially while they were fasting. By contrast, Nummenmaa, Hietanen, Calvo, and Hyona (2011, Experiment 2) found that such attentional orienting biases towards food items disappear when physical salience of the picture sets was strictly matched. Therefore, in order to obtain a comprehensive understanding of the attentional mechanisms involved in the processing of food-related cues, further studies with food compared to non-food pictures better controlled for visual saliency are needed in order to test whether healthy participants do have attentional biases.

Another crucial issue is the type of food stimuli used to measure visual attention. Although it has been suggested that the high-calorie content (Castellanos et al., 2009) rather the hedonic value of the taste might be responsible for the attentional biases, preferences for energy-dense foods differ depending on the taste value of specific food products. For instance, normal-weight subjects exhibit attentional biases as indexed by a larger proportion of initial fixations to high-calorie sweet (e.g., ice cream, chocolate cake) but not savory (e.g., bacon cheese burger, fried chicken meal) food pictures relative to low calorie images (e.g., sliced fruit, veggie wrap) when participants freely viewed pairs of images (Graham, Hoover, Ceballos, & Komogortsev, 2011). Consequently, it has been argued that the taste of food products influences attentional responses towards different kinds of fattening food. Unfortunately, the differential impact of taste and post-ingestive properties is difficult to determine from the current studies as the low-energy food pictures used as control are not satisfactory. In fact, since these low-energy control conditions are not usually matched with high-energy conditions for taste pleasantness or even include unpleasant bitter vegetables, they cannot rule out the possibility that heightened attention towards high-energy food pictures may be partly due to avoidance of the distasteful control pictures.

For these reasons, the present study is the first to examine the attentional responses of normal-weight subjects to the post-ingestive and/or orosensory attributes of the well-standardised food-related pictures, which were individually matched as closely as possible for size, brightness, contrast, complexity and spatial frequencies. In addition, the symptoms of disordered eating and differences in individual eating style (e.g., levels of restrained and external eating) were considered because they may influence attentional bias to food-related images either in combination with weight status or as a factor in itself (Doolan et al., 2015). Furthermore, reward responses and impulsivity were also controlled as individuals with high sensitivity to reward have been shown to be more prone to detect signals of reward in their environment and to approach them (Beaver et al., 2006). We thus used an eye-tracking approach due to its critical advantages over indirect methods such as the continuous measures of the orientation, maintenance and disengagement of visual attention to stimuli with acquired incentive salience; the unique and easily accessible window to examine how semantic knowledge modulates attentional responses to food because the rapid visual system's ability to access a wealth of knowledge about food attributes (Stevenson, 2009); and the same visual sensory modality for the input and output processes, allowing for tight control and interpretation of the temporal components (early/involuntary or later/voluntary attentional processes) and the direction of attention (approach or increasing attention versus avoidance or reducing attention) (Holmqvist et al., 2011). To measure difficulties in inhibition and attentional disengagement towards rewarding and aversive food cues, the well-established eye tracking antisaccade paradigm was selected, in which people are instructed to look away from a newly appearing neutral stimulus; while automatic attention orienting and conscious maintenance of attention towards food versus non-food pictures were simultaneously examined using another well-characterized eye tracking paradigm: free viewing (both previously used for studies in visual attention to food cues; e.g., Schag et al., 2013).

The guidance of our picture selection followed the Rozin and Fallon's (1986) psychological categories: high-calorie, good taste, distaste, danger and neutral non-food; which are based on knowledge (perceptual and semantic) about sensory properties of food, anticipated consequences of ingestion, and ideas about the nature or origin of the foodstuffs (see Appendix, Table A1). The high-calorie category referred to things people expect to have postingestive consequences such as feeling of fullness and satiation after eating high calorie food (e.g., cakes, potato chips) and whose tastes usually become liked; while the good taste category consisted of items with pleasant sensory effects in the mouth such as sweet sensations. In opposite to good taste, distaste category was included and referred to items with commonly unpleasant taste qualities including bitter, sour or irritants sensations (e.g., cabbage, broccoli or spinach). The danger category referred to food believed to have harmful consequences if ingested (e.g., nauseas, stomach discomfort) and considered as both distasteful and dangerous (e.g., rotten food). We hypothesized that items with higher relevance to survival (such as high-calorie and danger) should affect not only early/involuntary but also later/voluntary attentional processes with a tendency to initially and longer fixate on the food pictures. In addition, given the modulating effect of the sensory-hedonic properties on visual attention (Brignell, Griffiths, Bradley, & Mogg, 2009; Graham et al., 2011), approach/increasing attention by pleasant taste and high-calorie food as well as avoidance/reducing attention by unpleasant distasteful and danger content are expected.

2. Material and methods

2.1. Participants

A total of 44 students (7 men and 37 women) of the University of Fribourg (Switzerland) participated in our study and were compensated with course credits. All participants self-reported normal or corrected-to-normal visual acuity. The participants reported sociodemographic characteristics. Additionally, eating disorder pathology using the Eating

Table 1
Characteristics of male and female participants.

$N = 44$	Male	Female	P
Age (years)	23.29(1.38)	21.68(2.4)	0.09
Body mass index (kg/m^2)	22.28(1.65)	21.61(1.71)	0.34
Eating Disorder Examination—Questionnaire (EDE-Q)			
Shape concern	1.09(1.24)	1.50(1.20)	0.45
Weight concern	0.74(0.99)	1.09(1.02)	0.40
Restraint	0.43(0.37)	0.70(0.78)	0.38
Eating concern	0.20(0.38)	0.36(0.54)	0.46
Global	0.97(1.13)	1.77(1.07)	0.34
Dutch Eating Behaviour Questionnaire (DEBQ)			
Restrained eating	2.47(0.77)	2.97(0.59)	0.05
Emotional eating	2.56(0.64)	2.37(0.51)	0.40
External eating	1.17(0.68)	1.25(0.63)	0.75
Behavioural Inhibition System and Behavioural Activation System Scale (BIS/BAS)			
BAS Drive	10.28(1.60)	11.27(1.97)	0.22
BAS Fun seeking	8.14 (1.77)	9.27(1.69)	0.12
BAS Reward	16.71(2.88)	16.30(2.89)	0.60
BIS	17.71(3.87)	15.22(3.65)	0.03

Note. Mean and standard deviation (in parentheses). Clinical cut-off value of EDE-$Q_{Global} \geq 4$. Internal consistency of the scales (gender data collapsed): $\alpha = 0.90$ for EDE-$Q_{Shape\ concern}$, $\alpha = 0.83$ for EDE-$Q_{Weight\ concern}$, $\alpha = 0.72$ for EDE-$Q_{Restraint}$, $\alpha = 0.89$ for EDE-$Q_{Eating\ concern}$, $\alpha = 0.92$ for EDE-Q_{Global}; $\alpha = 0.84$ for $DEBQ_{Restrained\ eating}$, $\alpha = 0.84$ for $DEBQ_{Emotional\ eating}$, $\alpha = 0.80$ for $DEBQ_{External\ eating}$; $\alpha = 0.62$ for BAS_{Drive}, $\alpha = 0.65$ for $BAS_{Fun\ seeking}$, $\alpha = 0.61$ for BAS_{Reward}, $\alpha = 0.69$ for BIS.

Disorder Examination Questionnaire (EDE-Q4; Fairburn & Beglin, 1994), eating styles using the Dutch Eating Behaviour Questionnaire (DEBQ; Lluch et al., 1996), and sensitivity of reward and impulsivity using the Behavioural Inhibition System and Behavioural Activation System Scale (BIS/BAS; Caci, Deschaux, & Baylé, 2007) were assessed. Exclusion criteria were diseases/medication influencing weight/eating behaviour, eating disorders, diabetes, allergies or aversions to any of the food pictures used, 30 > age > 18 years, vegetarians, people reporting religious food prohibition and a body mass index, BMI, of below 18.5 or over 25.0 kg/m^2. The participant characteristics are depicted in Table 1. No significant differences were found in a multivariate generalized linear model analysis including age, BMI, EDE-Q4, BEDQ and BIS/Bas scores related to gender, except for DEBQ–Restrained eating and BIS scores. While mean scores of DEBQ, EDE-Q, BAS Drive and BAS Fun seeking were comparable to scores in other nonclinical samples (e.g., (Castellanos et al., 2009; Hilbert, Tuschen-Caffier, Karwautz, Niederhofer, & Munsch, 2007) and none of the participants scored above the cut off for clinical eating disorders (i.e., a global score of at least 4 on the EDE-Q; Mond, Hay, Rodgers, & Owen, 2006), BAS reward and BIS scores were lower compared with healthy aged-matched samples (Castellanos et al., 2009). The participants were informed of the general procedure and gave their written consent. The study was approved by the ethics committee of the Department of Psychology of Fribourg and the Ethical Committee of the Canton of Vaud (Switzerland).

2.2. Food images

2.2.1. Parameters of the image database

Except for one category, images were selected from a food picture database featuring food images with simple figure ground compositions for experimental research (Blechert, Meule, Busch, & Ohla, 2014; Table 2) and comprised non-food pictures and arousing food pictures according to Rozin and Fallon's (1986) classification: neutral (NE), high-calorie (HC), good taste (GT), distaste (DI) and danger (DA) foods (Fig. 1). The exception was the DA food pictures, which were not available in the Blechert et al.'s (2014) database and were selected from Internet sources. Physical image characteristics were computed using a customized script written in Matlab R2011b to account for the potential confounds of low-level visual properties (https://goo.gl/T1BzDw; Blechert et al., 2014) and matched for physical properties (Table A2), which did not differ in size, brightness, within-object contrast, complexity (edge detection) and spatial frequencies (Kruskal-Wallis tests; highest $c^2 = 9.4$, df = 4, $p > 0.05$). For a definition of the physical image properties size, brightness, within-object contrast, complexity and spatial frequencies, see Blechert et al.'s (2014). All pictures had the same resolution and colour depth (600 × 450 pixels, 96 dpi, 24 bpp) and were homogenous with regard to neutral (white) background.

The stimulus material consisted of 126 coloured pictures (36 for the antisaccade task and 90 for the free exploration task). BE pictures rated high in palatability, craving (i.e., desire-to-eat), valence (i.e., the feeling of pleasantness/unpleasantness towards a stimulus) and in calorie content; while GT pictures were related to high ratings for palatability, craving and valence but to low calories. By contrast, DA pictures rated low in palatability, craving and valence; while DI pictures rated low in palatability, craving and calories. Analyses of the database ratings and macronutrients showed significant differences accordingly (Kruskal-Wallis tests; lowest $c^2 = 9.4$, df = 4, $p < 0.05$; Appendix, Table A2). In order to establish the maximum separation possible (and according to kcal limits for foods sold outside of the middle and high schools; Robles, Wood, Kimmons, & Kuo, 2013), the criterion for high calorie content was fixed at > 250 kcal/100g, while low calories values were determined by foods with < 70 kcal/100g. Scores of palatability > 60, craving > 37 and valence > 55 were respectively considered as high palatable, high craving and pleasant food pictures; while scores of palatability < 45, craving < 26 and valence < 45 as low palatable, less desirable and unpleasant food pictures.

2.2.2. Subjective ratings of the images

Additionally, the participants also rated the pictures in terms of arousal (i.e., the degree to which one feels excited or activated by a stimulus), valence, palatability, craving, and negative post-ingestive consequences before completing the tasks. The analyses confirmed the effectiveness of the picture selection in our sample (see Table 3) showing significant differences in arousal (BE,GT,DI,DA > NE), valence (BE,GT > DI, NE > DA), palatability (BE,GT > DI > DA) and craving (BE,GT > DI > DA) as expected according to Blechert et al. (2014), as well as negative consequences (BA > BE > DI > GT) (ANOVAs with Greenhouse-Geisser correction and post-hoc comparisons with Bonferroni corrections; the lowest $F[3.19,137.16] = 48.46$, $p < 0.001$; $\eta 2 = 0.53$).

2.3. Experimental paradigms and eye-movement metrics

We used two eye movement paradigms to investigate: 1) the initial engagement of visual attention towards food/non-food pictures (antisaccade paradigm), and 2) the general visual attention towards different pictures in competition (free viewing paradigm).

In the antisaccade paradigm, pictures of each category appear randomly on the left or right side of the screen. Participants were instructed to look in the direction of the stimulus (prosaccade) or in the opposite direction of the stimulus (antisaccade) depending on the colour (red/green) of a previously presented dot, as fast as accurately they could (see Fig. 2A) according to the following instruction: "If a green dot appears on the screen, please look at the picture as fast as possible. If a red dot appears on the screen, please don't to look at the picture but to look in the opposite direction". The antisaccade paradigm was composed by 720 randomized trials; each image was presented 20 times after the red/green cue (12 blocks, each with 60 trials). The percentage of directional errors (incorrect pro/antisaccades over the total number of pro/antisaccades) and the latency of the first correct/incorrect saccade (saccadic reaction times from the onset of the image for the first correct/incorrect pro/antisaccade) represented automatic

Table 2
List of food pictures (code and food description) used in the current study.

Paradigm	List of pictures				
	HC	GT	NE	DI	DA
Antisaccade	4, 7, 27, 83, 111, 112	196, 197, 198, 199, 201, 531	1004, 1007, 1008, 1009, 1010, 1011, 1012, 1013, 1014, 1015 1016, 1018	262, 342, 368, 401, 520, 550	–
	Chocolate cookie, Croissants, bag of chips, filled chocolates, bar of chocolate with nuts, bar of chocolate	Salad plate, tomatoes bell peppers, raspberries, watermelon, salad plate	Shoe, brush, hair brush, red bucket, yellow bucket, light bulb, hammer, towel, cushion, clothes hanger, ladder, nails, paintbrushes	Celery, endives, artichoke, red chilli pepper, green chilli pepper, Brussels sprouts	Rotten bread, burnt slice of toast, rotten sausage, rotten salami, rotten meat filets, rotten chicken
Free exploration	173, 174, 179, 286, 287, 289, 290, 291, 293, 295, 344, 351, 416, 465, 474,	358, 365, 407, 442, 446, 452, 453, 460, 461, 467, 468, 482, 526, 528, 530	1022, 1128, 1232, 1135, 1137, 1031, 1032, 1033, 1035, 1036, 1038, 1058, 1059, 1080, 1092, 1095, 1098, 1129, 1130, 1131, 1132, 1198, 1200, 1202, 1208, 1145, 1218, 1219, 1222, 1223	228, 247, 251, 252, 254, 257, 260, 266, 276, 333, 360, 367, 405, 434, 449	–
	Chocolate filled with milk cream, croissant with butter and jam, pralines, pistachios, croissant, brownie with nuts, KitKat, Toblerone, chocolate cookies, white chocolate, chocolate truffle, bar of chocolate, chocolate (candy) bar, marble cake, chocolate pieces	Strawberry, half peaches, plate of salad, mixed salad, peach, raspberry, blackberry, tomato, peach, watermelon, tomato, sliced red bell pepper, blackberries, orange, glass of orange juice	Scissors, brown plant starter set, candle, bucket, lamb, sockets, telephone, clock, clock, books, sponge, hair brush, waste bin, sofa, shopping bag, paper bag, brown wallet, paper bag, screw and nuts, screw and nuts, tape, tape, toilet paper, watering can, suitcase, broom, books, closed chair, chair, garbage bin, wooden case	Artichoke, zucchini, lemons, green lettuce, green bell peppers, spring onions, Chinese cabbage, lettuce (iceberg), figs, bowl of salad, leek, asparagus, lettuce (lollo rosso) garden radish green onion (shallot)	Rotten salami, burnt nuggets, burnt chocolate cookies, rotten hotdog, rotten bread, rotten bread, cheese, chocolate bar, sausages, rotten chicken, toast, rotten salami, burnt cookies

Note. Number in the food-pics database (Blechert et al., 2014). DA pictures were not available in the food-pics database and were elaborated by our group. HC = sweet/savory high-calorie food; GT = sweet low-calorie foods; NE = non-kitchen household items; DI = low calorie items with unpleasant taste; DA = potentially noxious substance.

Fig. 1. A subset of the types of images used for high-calorie (HC), good taste (GT), neutral non-food (NE), distaste (DI) and danger (DA) categories.

attention orienting. In addition, the fixation duration after the first correct saccade and the time to correct directional errors in the first saccade represented conscious and maintained attention.

In the free viewing paradigm, participants were instructed to freely look at the two different images presented at the same time on the screen for 2000 ms (as previous studies using eye tracking; e.g., Priebe, Messingschlager, & Lautenbacher, 2015) (Fig. 2B) according to the following instruction: "Please look freely at the images". It was composed by 90 randomized trials, meaning 90 picture comparisons (each picture appears 2 times: once on the left and once on the right). According to Mogg, Bradley, Field, and De Houwer (2003), attentional orienting is represented by the fixation direction bias score, calculated as the percentage of trials when the first fixation was directed to the food pictures as a proportion of the total number of trials (scores > 50% reflect a bias in orienting towards food pictures relative to non-food pictures; 50% indicates no bias). Attentional engagement was measured by the fixation duration bias score, calculated by subtracting the mean duration of initial fixations on non-food pictures from the mean duration of initial fixations on food-related pictures (positive scores reflected more time spent looking at food-related pictures); and gaze duration bias score (Giel et al., 2011), calculated by subtracting the total gaze duration (sum of all duration fixations in an image per trial) on the food pictures from the total gaze duration on the non-food pictures (positive scores reflect the tendency to continuously pay attention to the food picture). It should be noted that the effects of food pictures were always compared using the neutral non-food (NE) as reference category in order to rule out the possibility that attentional responses, e.g., towards rewarding food pictures are rather due to avoidance of the aversive food pictures or that contrast category influences the context in which the relevant images are automatically evaluated.

2.4. Apparatus

Using the EyeLink® 1000 Desktop Mount system (SR Research Ltd., Ontario, Canada), eye position and eye movements were determined by measuring the corneal reflection and dark pupil with a video-based infrared camera and an infrared reflective mirror. The eye tracker had a spatial resolution of 0.01° of the visual angle, an average gaze position error of about 0.25°, and the signal was sampled and stored at a rate of 1000 Hz. Although the viewing was binocular, the recording was monocular (a standard procedure in eye-tracking studies). Calibration and validation of the measurements were performed before each experimental session using a nine-point fixation to adapt the eye tracker to the individual properties of the participants. If results weren't satisfying (drift correction > 1°), the procedure was performed again. The eye tracking tower with the chin and forehead pad was arranged 80 cm in front of a 60.9 cm computer screen with a resolution of 1920 × 1080 pixels (Dell U2412 M). Both antisaccade and free-exploration tasks were running using Matlab 7.10.0 (R2010a), EyeLink Toolbox and Psychophysics extensions.

2.5. Procedure

Before coming to the laboratory, participants completed online versions of the questionnaires. The additional subjective computer-based rating of all pictures was conducted. After a calibration and validation, the antisaccade task was performed first as it required more effort. The whole experiment was organized in two sessions of about 1.5 h each over two days, the first one serving to fill out the questionnaires and the second one involving the eye movement tasks. In order to control the motivational states, participants were asked not to eat or drink anything for 3 h prior to each test session (as used in previous studies on visual saliency bias in consumer choices; e.g., Milosavljevic, Navalpakkam, Koch, & Rangel, 2012), except water which was allowed up to 1 h before the lab session.

2.6. Data preprocessing and analysis

Artefact-contaminated trials and trials without saccades (e.g., failures to detect the pupil and eyeblinks) were subtracted from the total number of valid trials. Trials with latencies below 80 ms or above 700 ms after target onset were also excluded as they are considered as anticipatory or delayed (Fischer, Gezeck, & Hartnegg, 1997). The

Table 3
Additional subjective ratings of the food pictures.

Paradigm	Attribute		Category				
			HC	GT	NE	DI	DA
Antisaccade	Rating data	Palatability	64.64(11.77) ^{a}	59.58(11.98) ^{a}	–	45.82(14.8) ^{d}	4.92(2.78) ^{e}
		Craving	44.01(11.07) ^{a}	47.21(8.63) ^{a}	–	20.10(8.56) ^{d}	5.00 (2.78) ^{e}
		Valence	61.19(7.75) ^{a}	60.53(6.59) ^{a}	39.51(12.24) ^{c}	44.23(7.63) ^{d}	10.90(6.53) ^{e}
		Arousal	35.39(17.70) ^{a}	35.96(12.94) ^{a}	10.35(6.72) ^{c}	20.95(11.60) ^{d}	33.66(15.05) $^{a, e}$
		Negative consequences	50.38(8.70) ^{a}	10.36(5.34) ^{b}	–	18.18(8.50) ^{d}	68.00(13.64) ^{e}
Free exploration	Rating data	Palatability	62.25(15.98) ^{a}	64.55(8.15) ^{a}	–	42.01(14.99) ^{d}	4.78(2.53) ^{e}
		Craving	47.07(13.32) ^{a}	52.85(12.67) ^{a}	–	34.58(5.18) ^{d}	6.50(3.62) ^{e}
		Valence	54.70(16.04) ^{a}	60.49(18.90) ^{a}	42.08(10.20) ^{c}	42.06(18.32) $^{c, d}$	9.92(6.53) ^{e}
		Arousal	44.75(15.01) ^{a}	40.41(11.42) ^{a}	15.52(7.92) ^{c}	29.50(10.31) ^{d}	43.35(16.01) $^{a, e}$
		Negative consequences	26.99(10.37) ^{a}	15.02(8.60) ^{b}	–	15.37(13.63) $^{b, d}$	63.76(14.94) ^{e}

Note. Mean and standard deviation (in parentheses). Palatability (from "not at all" to "extremely"), craving (from "not at all" to "extremely"), valence (from "very negative" to "very positive"), arousal (from "not at all" to "extremely") and negative consequences (from "not at all" to "extremely"; considered as anticipated postingestive consequences such as the risk of sickness in eating the food in the picture) were rated using visual analogue scales (from 1 to 100). Values with different superscripts represent means that are statistically different; $p < 0.001$.

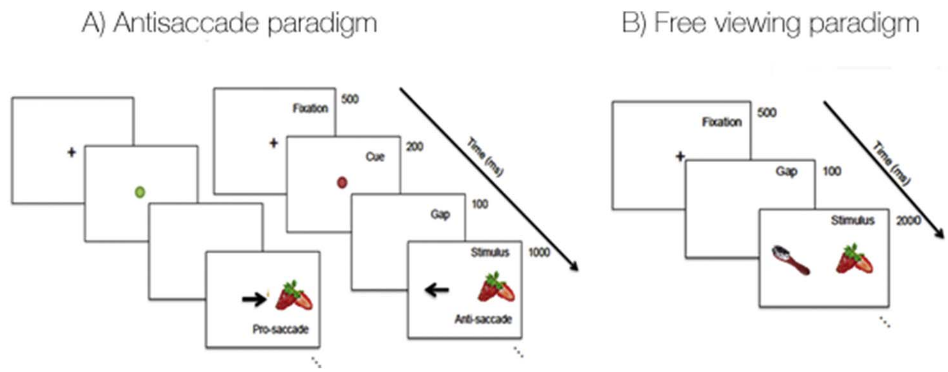

Fig. 2. Schematic representation of the antisaccade paradigm (A) and the free viewing paradigm (B). (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.)

percentage of invalid trials amounted up to 33.81 ± 20.01 (mean ± SD; average percentage anticipatory/delayed trials = 8.62) for the antisaccade and to 6.67 ± 7.84 (average percentage anticipatory trials = 4.93) for free exploration tasks. Although the percentage of anticipatory/early responses was similar to previous studies with participants aged 20–35 years (e.g., Klein, Fischer, Hartnegg, Heiss, & Roth, 2000), a large number of invalid trial was observed for antisaccade possibly as a result of fatigue and the difficulty of our task. On the basis of the number of valid trials, whether a picture category significantly affected eye-movement metrics of the antisaccade (percentage of directional errors, latency of the first correct saccade, fixation duration after the first correct saccade and time to correct directional errors in the first saccade) and free exploration (direction bias score, fixation duration bias score and gaze duration bias score) paradigms was tested using Linear Mixed-Effects Modelling (LMM) (Heck, Thomas, & Tabata, 2013; Maxwell & Delaney, 2004).

Hierarchical modelling was performed using LMM. The need for multilevel modelling of dependent variables was indicated by the intraclass correlation coefficient (ICC > 0.05) and the design effect (*deff* > 2) both showing dependency in the data (Hox & Balderjahn, 1998). LMM was fit to the data with random intercepts for participant and questionnaire scores. Picture category and gender are considered as fixed effects. All models were fitted using Maximum Likelihood with a full variance component structure. In the basic model, we applied a random intercept model with only picture category as fixed effect and participant as random effect. A step-wise procedure was then applied to construct the more detailed model. The following terms are added: 1) the gender of the participant as the fixed effect; 2) the interaction between gender and picture category as fixed effects; and 3) the questionnaires scores (i.e., EDE-Q, DEBQ, and BIS/BAS) as random effects. Model comparison was performed on the model log-likelihood. Concerning the fixed effects, the model predicting antisaccade metrics was significantly improved when gender was included (direction error; $\chi2_{\text{Change}} = 4.113$, $df_{\text{Change}} = 1$, $p < 0.05$), but not for free exploration metrics (higher $\chi2_{\text{Change}} = 1.01$, $df_{\text{Change}} = 1$, $p = 0.3$). On the other hand, no model was significantly improved when picture category x gender was added and neither model produced a significant picture category x gender interaction (Cohen's $d < 0.2$; following the Taylor (2014)'s approach); thus, the interaction was dropped from all subsequent analyses. Concerning the questionnaire scores as random effects, the model predicting antisaccade metrics was found to have a significantly better fit adding only EDEQ–Eating Concern and BAS-Reward scores (ps < 0.05). The questionnaires scores however did not substantially alter the model for free exploration (higher $\chi2_{\text{Change}} = 0.99$, $df_{\text{Change}} = 1$, $p = 0.32$). We thus reported the model fitting for antisaccade using Eq. 1 and free exploration metrics using Eq. 2. In all analysis, a significance level of α = 0.05 was adopted. Post-hoc factor level comparisons were calculated using a pairwise comparison method and the Bonferroni correction for multiple comparisons. When the tests of fixed effects did not have F distributions, the degrees of freedoms were adjusted by a Satterthwaite approximation. Analyses were performed using the MIXED procedure in SPSS (IBM SPSS Statistics 22).

$$Y_{ij} = b_{00} + b_{10} Picture\ Category_{ij} + b_{01} Gender_j + u_{1j} EDEQ{-}Eating\ Concern_j + u_{2j} BAS{-}Reward_j + u_{0j} + \varepsilon_{ij} \quad (1)$$

$$Y_{ij} = b_{00} + b_{10} Picture\ Category_{ij} + u_{0j} + \varepsilon_{ij} \quad (2)$$

3. Results

3.1. Antisaccade paradigm

The model only yielded a significant main effect for gender on antisaccade directional error rate (F(1,43.35) = 5.11, $p < 0.05$), showing higher rates in females (32.9%) compared to males (20.5%) (b = −12.4, t(43.36) = 2.26, $p < 0.05$). Concerning the effect for picture category, the means for both pro- and antisaccades metrics are presented in Table 4 and the results from the model's estimate are displayed in Fig. 3 (see also Appendix, Table A3). The analysis showed a significant main effect of picture category on the percentage of directional errors for antisaccade (F(4176) = 2.92, $p < 0.05$), latency of the first correct prosaccade (F(4176) = 8.27, $p < 0.001$), fixation duration after the first correct prosaccade (F(4176) = 8.12, $p < 0.001$) and time to correct directional errors in the first antisaccade (F(4176) = 135.20, $p < 0.001$). No significant effects were found on the percentage of directional errors for prosaccade, latency of the first correct antisaccade, fixation duration after the first correct antisaccade and time to correct directional errors in the first prosaccade

Table 4
Metrics for pro- and antisaccade as a function of the picture category.

Trial	Picture category	Direction errors (%)	Latency of the first correct saccade (msec)	Fixation duration after the first correct saccade (msec)	Time to correct directional errors in the first saccade (msec)
Antisaccade	HC	32.3(16.4)	172.9(39.0)	759.5(39.9)	80.4(14.2)
	GT	31.3(17.0)	173.0(42.5)	759.3(43.1)	83.3(12.9)
	DI	29.6(15.1)	178.4(37.6)	754.9(38.9)	58.4(10.5)
	DA	32.1(16.5)	175.7(42.5)	756.7(43.2)	84.5(14.8)
	NE	30.7(14.4)	177.7(40.0)	755.8(39.4)	83.9(13.7)
Prosaccade	HC	5.4(4.9)	137.8(25.4)	804.9(25.7)	66.3(10.7)
	GT	5.4(4.7)	136.8(26.1)	805.5(26.3)	70.1(10.3)
	DI	7.2(6.3)	143.3(25.7)	799.4(26.2)	66.0(9.9)
	DA	5.6(4.1)	141.3(24.9)	801.2(25.9)	67.9(9.5)
	NE	5.8(4.1)	144.3(26.1)	797.5(26.6)	68.1(9.9)

Note. Mean and standard deviation (in parentheses).

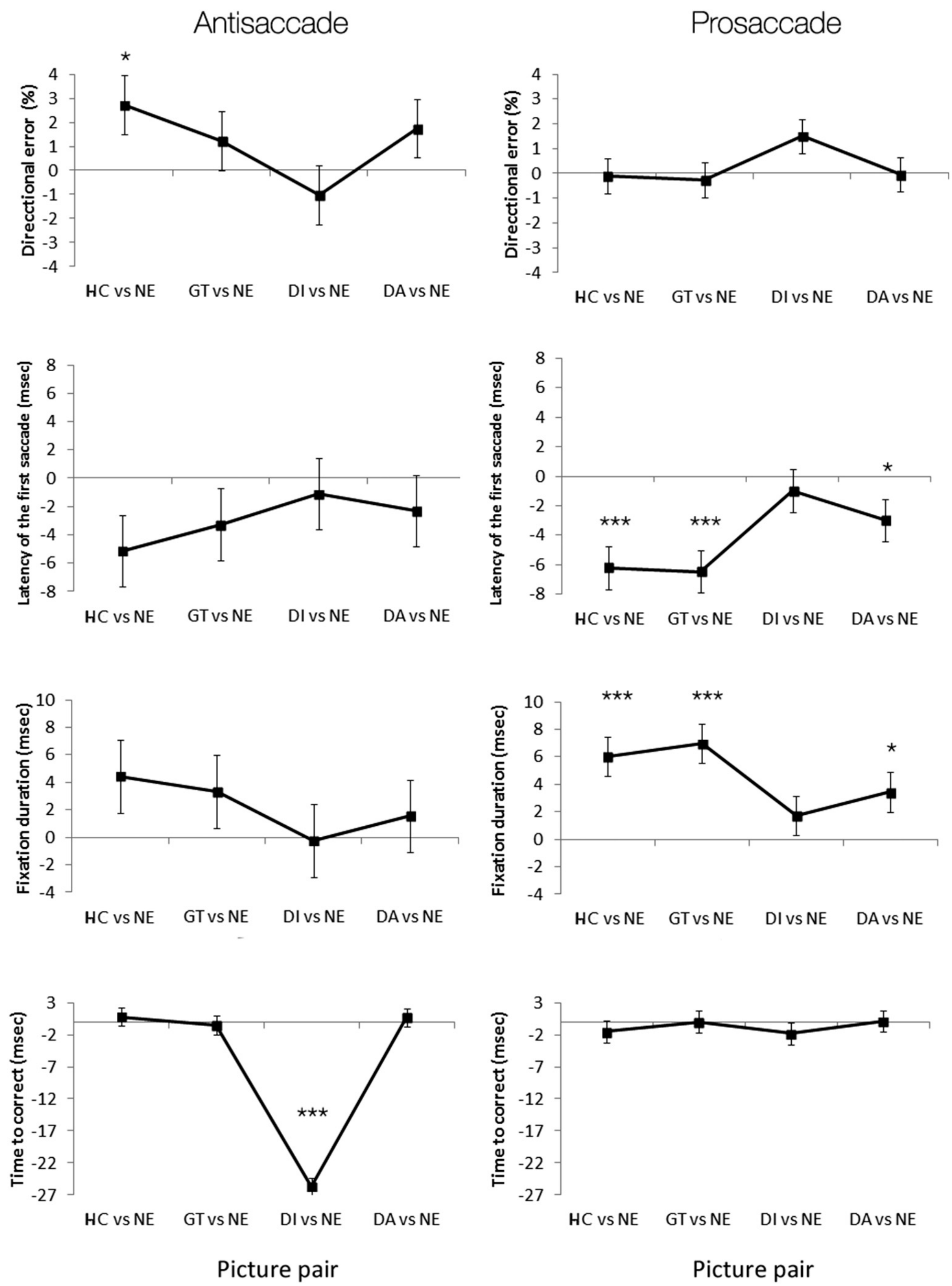

Fig. 3. Antisaccade-paradigm. The model's estimates for percentage of directional errors, saccadic reaction time of the first correct saccade, fixation duration after the first correct saccade, and time to correct directional errors in the first saccade obtained for both (left) pro-saccades and (right) anti-saccades as a function of picture type (high-calorie [HC], good taste [GT], distaste [DI] and danger [DA] categories compared with neutral non-food [NE]). Bars indicate standard errors. $^{*}p < 0.05$, $^{***}p < 0.001$.

(the highest F(4176) = 2.16, $p = 0.075$). Compared to the control pictures (NE), the analyses of the significant effects showed that directional error rates for antisaccade were higher in BE (b = 2.72, t(176) = 2.24, $p < 0.05$); the latency or reaction time of the first correct prosaccade was shorter in BE (b = −6.20, t(176) = −4.26, $p < 0.001$), GT (b = −6.47, t(176) = −4.26, $p < 0.001$) and DA(b = −2.98, t(176) = −2.01, $p < 0.05$); the fixation duration after the first correct prosaccade was longer in BE (b = 6.03, t(176) = 4.16, $p < 0.001$), GT (b = 6.95, t(176) = 4.83, $p < 0.001$) and DA(b = 3.44, t(176) = 2.39, $p < 0.05$); whereas time to correct directional errors in the first antisaccade was longer in DI (b = −25.72, t(176) = −18.19, $p < 0.001$). Post-hoc analyses did not show any difference among BE, GT and DA in reaction time of the first correct prosaccade or fixation duration after the first correct prosaccade (ps > 1). Finally, it should be noted that, even after controlling for between participant variability via EDEQ-Eating Concern and BAS-Reward scores, the relationship between picture category and the time to correct directional errors in the first antisaccade showed significant variance in intercepts across participants (var[u_{0j}] = 0.11, Wald Z = 4.12, $p < 0.001$).

3.2. Free exploration paradigm

Mean fixation direction bias score, fixation duration bias score, and gaze duration bias score as a function of the food pictures compared with neutral non-food (NE) as reference category are presented in Fig. 4. According to the model (see Appendix, Table A4), the picture category showed a significant effect on the fixation direction bias score

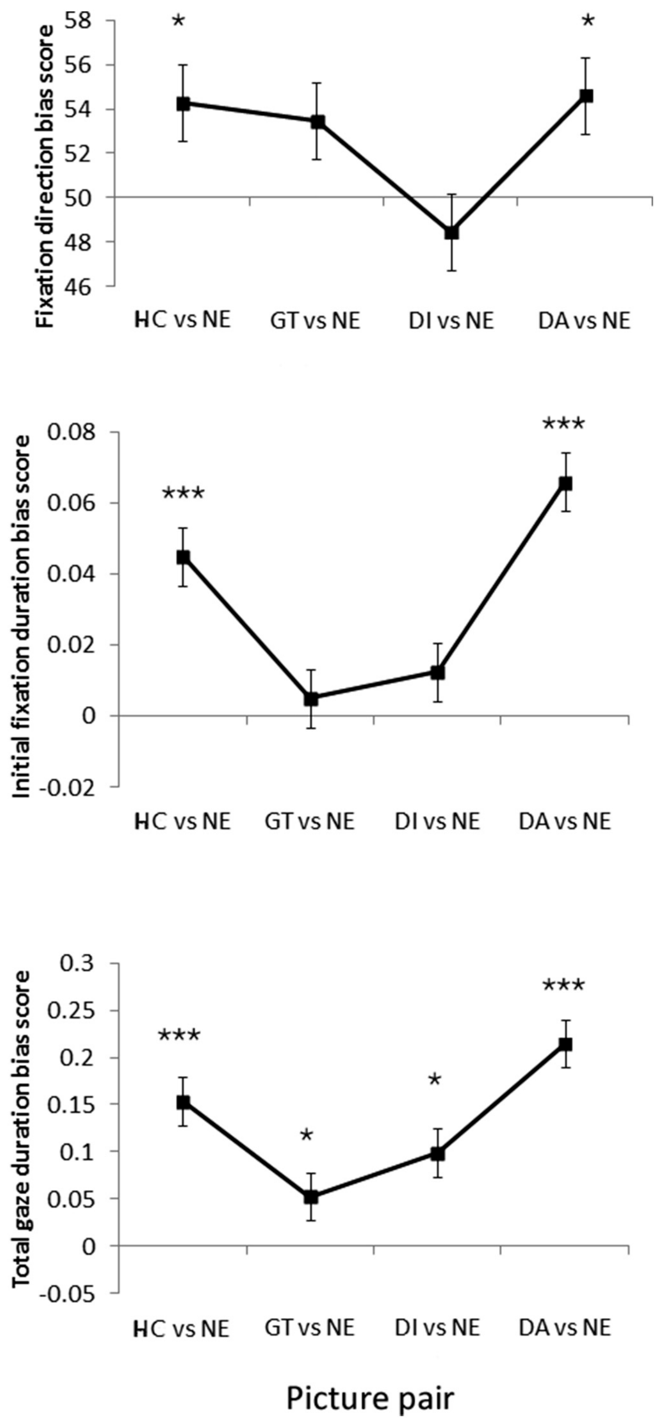

Fig. 4. Free exploration paradigm. Mean scores of fixation direction bias, fixation duration bias and gaze duration bias as a function of the food pictures compared with neutral non-food (NE) as reference category. Bars indicate standard errors. Values next to the horizontal lines represent no bias relative to neutral non-food controls.*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, indicating that bias scores differed significantly from the "no bias" value.

($F(3176) = 2.78$, $p < 0.05$), initial fixation duration bias score ($F(3132) = 14.46$, $p < 0.001$) and total gaze duration bias score ($F(3129.38) = 8.92$, $p < 0.001$). Compared with the bias towards GT pictures, the analyses only showed significant lower fixation direction bias to distasteful DI pictures ($b = -4.97$, $t(176) = -2.05$, $p < 0.05$), as well as a longer initial fixation duration and a longer gaze duration to BE ($b = 0.04$, $t(132) = 3.78$, $p < 0.001$ and $b = 0.10$, $t(129.2) = 3.00$, $p < 0.01$, respectively) and DA pictures ($b = 0.06$, $t(132) = 5.76$, $p < 0.001$ and $b = 0.16$, $t(129.2) = 4.70$, $p < 0.01$, respectively). Pairwise post-hoc comparisons did not reveal any difference between pictures categories with post-ingestive consequences (BE and DA) across the different types of bias ($p > 0.30$), but did between DA and DI in fixation duration and total gaze duration biases ($p < 0.05$). Concerning the random effect, the relationship between picture comparison and each dependent measure showed significant variance in intercepts across participants (the lowest var. $[u_{0j}] = 0.02$, Wald $Z = 1.88$, $p = 0.06$). Additionally, *t*-tests were separately performed in order to determine whether these bias scores differed significantly from the "no bias" value. Participants showed a significant tendency in direction bias towards BE and DA (the lowest $t(43) = 2.65$, $p < 0.05$) but not towards GT or DI (the higher $t(43) = 1.75$, $p = 0.085$). In fixation duration bias, the tendency was towards BE and DA (the lowest $t(43) = 5.68$, $p < 0.001$); and towards all food-related picture categories in total gaze duration bias (the lowest $t(43) = 2.42$, $p < 0.05$).

4. Discussion

We examined whether pictures associated with the positive/negative hedonic evaluation of taste and post-ingestive consequences affect visual attention processes in normal-weight people, by investigating how rewarding and aversive food attributes differentially modulate eye movements. This question was addressed by using an antisaccade and a free viewing paradigm, in which the incentive salience of the four food picture data sets elicited significant differences in gaze bias scores compared with neutral non-food categories. Congruent with our first hypothesis, we observed early and later attentional tendencies to items with post-ingestive consequences regardless of whether there are high-calories or dangerous content. Indeed, prosaccade latency and fixation direction bias score confirmed a higher initial attentional orientation towards HC (high energy sources) and DA (possible dangers) items. Also, the results in prosaccade fixation duration and initial fixation duration bias score reflected a maintained attention to HC and DA. These findings should come as no surprise considering that the primary functions of the brain include identifying biologically relevant stimuli such as nutritious food and poisonous/harmful substance and assigning these stimuli a processing priority, in which the sense of vision plays a central role (Stevenson, 2009).

According to the second hypothesis, the modulatory effect of the sensory-hedonic properties on visual attention, our results partially supported the impact of the affective taste valence of the pictures on visual attention. When strong post-ingestive components were absent, participants showed attentional approach to pleasant GT items with shorter reaction times and longer fixation duration for prosaccade. The motivational power of good taste was however inconsistent across the tasks showing no differences (antisaccade) or lower scores (free exploration) in comparison with highly palatable and calorically dense foods. Another interesting finding relies on the avoidance shown to unpleasant DI in terms of shorter time reactions (≈ 58 msec) to correct an incorrect prosaccade under antisaccade instructions. This avoidance for distasteful stimuli such as bitter vegetables or pungent chilli products was also suggested by the reduced antisaccade error rates (< 30%) and the score < 50 in fixation direction bias, although both trends were not significant. On the other hand, when post-ingestive attributes were present, the expected down-modulating effect of the unpleasant taste could not be observed on DA items compared with HC in early or later attentional measures; but only inferred indirectly via antisaccade directional errors: the participants were more able to disengage attention from DA than HC pictures. Taken together, the orosensory-hedonic value of the taste seems to play a relative minor role with respect to visual attention to cues with survival relevance. These affective taste aspects might rather operate during the subsequent processing of food objects associated with decision-making (starting at ~ 300 ms post-stimulus) (Toepel et al., 2009).

With regard to HC items, the higher attention may result from the interaction of the two different aspects of food reward that have been shown to activate the brain's reward system: pleasant taste and caloric content (e.g., Avena, 2015; Rolls, 2007). Indeed, when the visual food cues are made more salient through the use of images of foods of high hedonic value (e.g., chocolate, bacon) compared with hedonically neutral foods (e.g., cereal, bread) in thin individuals, robust and lasting activation of visual processing and attention-related cortical regions is observed (Cornier, Von Kaenel, Bessesen, & Tregellas, 2007). Anyhow, studies that have used either indirect methods (Gearhardt, Treat, Hollingworth, & Corbin, 2012; Phelan et al., 2011) or direct methods such as eye-tracking (Castellanos et al., 2009) agree that caloric content and/or metabolic effects of nutrients elicit stronger involuntary and attentional engagement responses than other visual stimuli, reporting increased initial and maintained attention to palatable energy-dense as compared with low energy density food (e.g., fruit and vegetables) in normal weight groups. However, unlike these studies which included aversive tasting foods (e.g., bitter vegetables) as a misleading control condition, the present work with more appropriate neutral non-food controls did allow to rule out the alternative explanation that computation of the attentional bias score towards high-energy food might rather be explained by attentional avoidance of DI items. Methodologically, it should be noted that food can be categorized on multiple dimensions (e.g., organoleptic attributes, food safety, nutritional value, functionality, healthiness or psychological factors); and different choices in picture sets could have created difficulties in terms of comparability of findings and contributed to mixed findings. In fact, it is possible that the contrast category influences the context in which food is automatically evaluated (Werthmann et al., 2015). For instance, presenting high-energy food together with low-energy food, might prime participants with beliefs/attitudes about the unhealthy value of fattening food, whereas comparisons between high-energy and neutral non-food stimuli should minimize this effect (Roefs et al., 2006; Werthmann et al., 2015). To the best of our knowledge, there has been just one previous study assessing pairs of images containing high-energy-density foods vs. non-food matches and low-energy-density foods vs. non-food matches, confirming that high-energy-density foods attract more attention (Doolan, Breslin, Hanna, Murphy, & Gallagher, 2014).

Despite previous work reporting that higher attentional responses to pleasant food images (Brignell et al., 2009; di Pellegrino et al., 2011), the present study is the first using eye movement to monitor attentional processing to examine the role of the hedonics of taste besides the nutritional and energetic content. Furthermore, the design of the present study allowed to explore the impact of the positive (e.g., sweet fruits) and negative (e.g., bitter vegetables) hedonic value for food regardless of the post-ingestive content, filling this gap in the literature. In this sense, it is somewhat paradoxical that most published studies examining gaze behaviour in consumer choice context with healthy samples have a special focus on package design and food labels (e.g., Ares et al., 2013; Bialkova & van Trijp, 2011) while the principal features motivating acceptance or rejection such as the taste (sensory) properties of a substance are neglected. Up to now, no study has either attempted to understand the attentional impact of our present danger category condition or the anticipated harmful consequences of ingestion in consumer choice. This applies for many relevant items such as potential allergens or carcinogens that may be also listed in the danger category. Investigating these circumstances is especially pertinent to complete our understanding of the (dis)like for foods and thus consumer choice due to impact of visual attention, e.g., in decision making (Orquin & Loose, 2013), of the strong correlations between gazing behaviour and food choice (Danner et al., 2016) and of the relationship between the total fixation duration and preference formation (van der Laan, Hooge, De Ridder, Viergever, & Smeets, 2015).

Nevertheless, more questions remain unanswered. Although it has been stated that the taste of high calorie food products may increase attentional biases to different kinds of fattening foods (Graham et al., 2011), it remains completely unexplored how much attention is directed and allocated when it comes to unpalatable high-fat food. In this sense, eye movements-based studies on distasteful substances with post-ingestive physiological effects such as alcohol products (e.g., beer or wine) may provide important information. For instance, heavy (Miller & Fillmore, 2010) and light drinkers (e.g., when beer is expected imminently; Field et al., 2011) maintain their gaze longer on alcohol-related compared to on control picture. From these results, it appears that rewarding post-ingestive determinants such as psychoactive and metabolic effects may overcome the unpleasant oral component. In any case, future research is needed in order to clarify the role of calories alone in attentional biases to food cues.

Finally, some limitations should also be taken into account. Firstly, while factors that have been recognised as having the potential to impact on attentional processing of visual food cues such as individual eating style trait, weight status, level of food deprivation and the energy density of food-related stimuli were considered, additional hunger level during the experiment was not reported. As the participants were refrained from eating for 3 h prior the experiment, one possible reason for the increased visual attention towards high-calorie foods might be that the participants were hungry. However, previous studies on the impact of hunger on food cue processing did not reveal an effect of hunger with up to four hours of fasting prior to the experiment (cf. van der Laan, De Ridder, Viergever, & Smeets, 2011). Secondly, the ideational dimension related to cultural reasons, and predominant in food rejections (e.g., disgust to pork for religious reasons and meat for vegetarians) (Rozin & Fallon, 1986), was controlled avoiding pictures of meat and excluding participants with moralization/religious food prohibitions. Nevertheless, it would be helpful for future research to further examine how symbolic and ideational cultural meanings impact on attentional biases towards food pictures. Finally, although the model predicting antisaccade metrics was significantly improved when gender was included and the composition of the sample did neither lead to increased Type 1 errors nor did it influence estimates (one thousand-sample bootstrapping; $P = 0.001$, 95% IC 0.10–0.14), the number of male subjects was too small to draw reliable and representative conclusions about gender differences.

5. Conclusion

Our findings indicate that eye movements are modulated by both the accepted and rejected food attributes. Even more important it is the result that normal-weight, non-eating disordered and non-food-deprived participants exhibit food-related attention biases especially for palatable high-fat food cues, as well as an avoidance of distasteful items. Since people who detect more rapidly and increase attention to energy dense food-related cues and avoid healthy unpleasant food such as bitter vegetables are thought of as being prone to overeating, understanding how food images interact with the brain's reward system to direct visual attention is of practical, ecological and environmental importance in determining the role of food cues in eating behaviour. Furthermore, the importance of filling this gap becomes more and more crucial as attentional biases towards food cues may influence cravings, food choice and food consumption and therefore be implicated as a risk factor for eating disorder and/or weight-related problems in the food cue-rich environment of today.

Conflict of interest

The authors have no conflict of interest to declare.

Acknowledgments

We thank Nicole Bianchi for her assistance with participant recruitment and data collection for this study. This work was partly supported by the Swiss Government (awarded to D. Garcia-Burgos) under the program "Swiss Government Excellence Scholarships for Foreign Scholars" (Ref. Nº 2013.0404, 2013–2014).

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.foodres.2017.04.011.

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