Does odour priming influence snack choice? – An eye-tracking study to understand food choice processes

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ABSTRACT

Awareness of food sensory cues in our surroundings may influence our eating behaviour in different ways. For example, exposure to non-consciously perceived odours may influence food choice but not appetite. Moreover, this type of exposure may mainly influence the food choice of starters or desserts but not of main courses. This infers that odour priming may influence impulsive or rewarding food choice but may not overrule our habits concerning the choice of a main meal. It is crucial to understand the role of odour priming on eating behaviour and how people can be steered towards healthier options. Implicit measures, such as visual attention, may be central to understand the food choice process. Therefore, we aimed to determine how non-conscious exposure to odours affect congruent snack choice (i.e. with similar taste characteristics) and whether this is modulated by visual attention. A total of 53 healthy young adults took part in a cross-over study which consisted of two test sessions. In each test session, they were non-consciously exposed to an odour that is associated to a sweet or savoury food. Visual attention was investigated by means of a wearable eye-tracker and subsequent snack choice was (covertly) measured. Our results showed that congruent snacks were fixated on first. However, sweet snacks were fixated on more frequently, and for a longer period of time, and were chosen most often, irrespective of the type of odour exposure. Our findings indicate that odour priming might steer the initial orientation towards congruent foods, but other factors (e.g. cognitive) may overrule its effect on the final choice.

1. Introduction

One of the main public health concerns is how to steer people towards healthier eating habits (Vecchio & Cavallo, 2019). Appetite, and even meal initiation, may be triggered by sensory cues such as food odours (Smeets & Dijkstra, 2014; Yeomans, 2006; Zafra, Molina, & Puerto, 2006). However, conscious and non-conscious odour exposure may differentially impact eating responses (Boesveldt & de Graaf, 2017; McCrickerd & Forde, 2016; Smeets & Dijkstra, 2014).

Non-conscious exposure to ambient odours may also act as a prime and lead to choosing congruent foods (Chambaron, Chisin, Chabanet, Issanchou, & Brand, 2015; de Wijk & Zijlstra, 2012; Gaillet-Torrent, Sulmont-Rossé, Issanchou, Chabanet, & Chambaron, 2014; Gaillet, Sulmont-Rossé, Issanchou, Chabanet, & Chambaron, 2013). For example, a non-consciously (or non-attentively) perceived fruity odour led to a greater selection of fruity desserts compared to the control (Gaillet-Torrent et al., 2014). Interestingly, previous research seems to suggest that odour priming may primarily influence food choice of starters (Gaillet et al., 2013) or desserts (Chambaron et al., 2015; Gaillet-Torrent et al., 2014) but does not influence the main meal (Morquecho-Campos, de Graaf, & Boesveldt, 2021; Mors, Polet, Vingerhoeds, Perez-Cueto, & de Wijk, 2018). Taking these findings together, we speculated that odour priming mainly influences the choice of rewarding foods, such as snacks, but does not impact the choice of a main meal, which is related to habits and dietary patterns.

Beyond explicit measures, such as self-reported appetite ratings, the use of implicit measures, i.e. reaction time or eye-movements, could lead to a better understanding of actual eating responses and the food choice process (Ayres, Conner, Prestwich, & Smith, 2012; De Houwer & Moors, 2016; Finlayson, King, & Blundell, 2008; Wang, Cakmak, & Peng, 2018). Compared to explicit measures, implicit measures can register automatically triggered responses (such as food cravings) that people are unaware of (Winkielman, Berridge, & Wilbarger, 2005). Thereby implicit measures could provide unique insights into automatic processes that happen outside the people’s conscious awareness, such as influences of (odour) priming.

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In the last decades, eye-tracking, which allows exploration of human behaviour in naturalistic environments, has been used as a reliable and well-validated tool to investigate eye movements (Casado-Aranda, Sánchez-Fernández, & Ibáñez-Zapata, 2020; Rayner, 1998). Eye-movements of relevance are fixations, periods in which the eyes rest relatively still on a certain location. During fixations, the fixated location appears at the fovea, the place in the retina that has the greatest visual acuity (Provis, Dubis, Maddess, & Carroll, 2013). Because locations outside of the fovea cannot be perceived in detail, usually it is supposed that visual attention is directed to the location of fixation. Therefore, visual attention is said to be “overt” and measurable with eye-tracking. Eye-tracking provides the ability to calculate the exact time, location and duration of these fixations. Moreover, eye-movements are linked to perceptual and cognitive processes that reflect visual attention (Duchowski, 2007; Hayhoe & Ballard, 2005; Orquin and Mueller Loose, 2013; Rayner, 1998).

Eye movements are thought to be of importance to the decision-making process (Orquin & Mueller Loose, 2013). For instance, the ‘gaze bias theory’ suggests that items that are chosen, are gazed at for longer (Pieters & Warlop, 1999; Schottor, Berry, McKenzie, & Rayner, 2010). However, it is still unclear if this theory applies to food items as well. The studies conducted on food items showed contradictory results. For example, Wang et al. showed that food choice, by means of an ad libitum buffet, was not predicted by total fixation time (Wang et al., 2018). In contrast, Armel and collaborators found that manipulating the time of fixation may influence choice, i.e., products were chosen more frequently upon a longer fixation compared to shorter fixation (Armel, Beaumel, & Rangel, 2008). Other researchers have suggested that the direction of the first gaze, but not the total fixation time, predicts consumption (Werthmann et al., 2011), while others did not find a relation between first fixation and choice (van der Laan, Hooge, De Ridder, Viergever, & Smeets, 2015).

A variety of studies have used eye-tracking in order to assess factors that affect visual attention to food products. Some of these studies used priming in order to influence visual attention. In the study of van der Laan et al., visually priming a health goal increased the participants’ visual attention towards healthy, low-energy food products (van der Laan, Papis, Hooge, & Smeets, 2016). Manippa, van der Laan, Brancucci, and Smeets (2019) showed that visual priming with unhealthy body shapes influenced female participants’ attention to high-calorie foods (Manippa et al., 2019). Furthermore, Peng-Li and collaborators showed that taste-congruent soundtracks influence congruent visual attention and food choice (Peng-Li, Byrne, Chan, & Wang, 2020). Until now, only one eye-tracking study used an olfactory stimulus to influence visual attention to food products. Through a screen-based eye-tracking experiment, Seo, Roidl, Müller, and Negoius (2010) found that upon attentive exposure to orange, lavender, coffee or liquorice odour, participants fixated pictures of corresponding objects longer and more frequently. However, it is not yet known how inattentive odour priming affects visual attention to actual food products in a more naturalistic setting and how it subsequently impacts food choices.

To further characterize the effects of odour exposure on the process of food choice, we here investigated the influence of non-consciously perceived odour exposure on visual attention and food choice. Further, we aimed to predict food choice by visual attention metrics. We hypothesized that visual attention metrics (first fixation location and duration, fixation count, and total fixation duration) and food choice would be congruent with the exposed odour: e.g., visual attention and food choice would be in favour of sweet snacks (i.e., chocolate bars or bubble-gums) compared to savoury snacks (chips or meat snacks) after non-conscious exposure to sweet odours (i.e., chocolate or bubble-gum) and vice versa. Moreover, our secondary objective was to explore whether the effect of odour priming on food choices could be predicted by visual attention and snack attributes (i.e., liking and familiarity of the snacks), either whether snack attributes could directly predict food choice or whether snack attributes could influence visual attention which in turn could predict food choice.

2. Materials and methods

2.1. Participants

2.1.1. Participant recruitment

People of different nationalities between 18 and 35 years old were recruited within the Wageningen area via social media. Potential participants provided their informed consent and filled out the online screening questionnaire – via EyeQuestion® (Version 3.11.1, Logitic BV) – to determine their eligibility. The screening questionnaire consisted of questions regarding general lifestyle and medical information, and a colour blindness test (Ishihara, 1951). Also, eating behaviour, by means of the Dutch Eating Behaviour Questionnaire (DEBQ), impulsiveness, by the Barratt Impulsiveness Scale (BIS-11), and behavioural approach system, via the Behavioural Activation System scale (the BAS (Carver & White, 1994)), scores were assessed. These behaviour measures reflect certain personal responses towards food and general reactions and therefore we used them as covariates. Inclusion criteria consisted of: body mass index (BMI) between 18.5 and 30 kg/m²; fluency in English; full colour vision as determined by the Ishihara’s colour test (Ishihara, 1951); and self-reported normal vision or use of contact lenses. Exclusion criteria consisted of: eye limitations or a history of medical eye procedures, such as any eye surgery (e.g. corneal surgery), or dependence on any type of (bifocal) glasses; habitual smoking; any dietary restriction, allergy, intolerance, or oversensitivity to food used in this study; use of medication other than occasional use of pain medication (such as paracetamol and NSAIDs) or monophasic birth control; pregnancy; breastfeeding; participation in other medical studies; or participation in our previous studies (Morquecho-Campos, de Graaf, & Boesveldt, 2020).

2.1.2. Participant characteristics

Sixty participants were included in the study. However, 57 participants completed the two test sessions. Of those, four participants were excluded from the data analysis: two participants did not fulfil the inclusion criteria (anymore) and two guessed the goal of the experiment (as became clear from the debriefing session). Therefore, 53 participants (39 females and 14 males; 24.4 ± 3.3 years old; BMI of 22.6 ± 2.1 kg/m²) were included in the analysis. Further characteristics of the participants can be found in the supplementary materials (Table S1), showing that the participants do not frequently engage in overeating, impulsive and rewarding behaviours. Participants were compensated for their contribution at the end of the study. The study was conducted in accordance with the Declaration of Helsinki (revised in 2013) and approved by the Medical Ethical Committee of Wageningen University (NL51747.081.14).

2.2. Stimuli

2.2.1. Odour stimuli

Odours were selected to represent taste qualities: sweet and savoury. The odours were distributed in air-conditioned rooms by means of vaporizers (Iscent, Zeewolde, The Netherlands). Pilot studies were conducted in order to determine the proper odours to be used and their concentrations. We aimed to achieve a perceived intensity of 35–50 mm on a visual analogue scale (VAS), which should be non-consciously (or inattentively) perceived by participants who were kept naive to the odour exposure. The pilot studies consisted of several short sessions where participants – who did not participate in the actual study – were exposed to an odour dispersed in one of the rooms. At least five
participants took part in each condition. Participants were asked about their awareness of any odour present in the room, and if so, to assess the odour’s intensity on a 100 mm VAS (‘Not at all’–‘Very’), and to identify the odour and its taste category (sweet, savoury, or neutral). Based on the outcomes, we selected two odours per category and determined suitable intensities: bubble-gum (International Flavour and Fragrances, IFF SC753057; 3% in propylene glycol, PG) and chocolate (IFF 10810180; 60% in PG) for the sweet category; chips (Symrise 769462; 100%) and duck (meat) (Symrise 619322; 2% in PG) for the savoury category. The final dispersion frequency and perceived intensity of the odours can be found in the supplementary materials (Table S2).

Odour stimuli were prepared in advance and stored in the fridge until the morning of the test session. In the morning of the test session, the odour stimuli were stored at room temperature until the test session.

2.2.2. Snack products and food area

A pilot study was conducted to determine the familiarity, liking, and sweet or salty/savoury association of different potential snacks. Additionally, the percentage of respondents that have previously consumed the snack was assessed. These snacks were selected to match the available odour options (bubble-gum and chocolate for the sweet category and chips and duck (meat) for the savoury category). Sixty-three people living in the Netherlands, aged between 18 and 39 years old, completed the online survey (Qualtrics®, USA). Based on the results (see results in supplementary materials Table S3), we chose 12 food products (6 per taste category; 3 per taste sub-category) that are commonly recognized by people living in the Netherlands. The snack versions of these products were selected and used for the food area. The products and their description can be found in Table 1. Table 1 also shows that the vast majority of the snack products were similar in energy density, with the exception of Skittles and Bifi that consist of a lower energy density.

The snack products were placed in a doorless mini fridge (88 L; 82.5 (h) × 43 (w) × 48 (d) cm). Product placement has been shown repeatedly to influence visual attention (<u>Chandon, Hutchinson, Bradlow, & Young, 2009</u>; <u>Sütlüterin, Brunner, & Opwis, 2008</u>, accordingly, product placement was randomized over blocks and test sessions. The 12 snacks were distributed over 12 spots in the mini fridge (3 items per row in the 4 available rows). Three main criteria were followed to select suitable randomized schemes to prevent bias in attention and choice due to product-placement effects: 1) two snacks which belong to the same brand and category should not be next in line to each other to increase the perceived diversity; 2) the first (upper left) and the last (lower right) product had to be incongruent in taste, as people have a tendency to remember the first and the last product in a series best (<u>Chandon et al., 2009</u>; <u>Dayan & Bar-Hillel, 2011</u>) – for example, if the top left product was sweet in taste, the bottom right had to be savoury; 3) the same incongruency criteria should be applied for the two products in the centre of the food area (mid products in row two and three), as people have the tendency to pay attention to and choose products more often that are in the center of a shelf (<u>Atalay, Bodur, & Rasolofoarison, 2012</u>; <u>Chandon et al., 2009</u>). By placing taste-incongruent snack products in these specific areas, and by randomizing product placement in general, biases in attention and choice due to product-placement effects are diminished (<u>Mantonakis, Rodero, Lesschaeve, & Hastie, 2009</u>). Furthermore, we attempted to equalize the surface area of the snacks by piling-up smaller-sized snack items to form a stack. These size-adjustments were done because it has been demonstrated that surface size influences stimulus driven (bottom-up) attention and therefore plays a role in decision making (<u>Marchiori, Cornelle, & Klein, 2012</u>). A visual representation of the food can be found in Fig. 1 – Room 2.

The mini fridge (food area) was placed on a table adjustable in height. The height of the table was matched to the participants’ body height in order to assure a horizontal angle of view to the central area of the mini fridge.

2.3. Procedure

The study followed a randomized and balanced within-subjects block design. Participants visited the test location two times, once for each test condition (sweet and savoury odour). Participants were only exposed to one odour per taste category in a counterbalanced order. Individual test sessions took place in the afternoon after lunch time (14.00–17.00 h; four time slots per day) and were held with at least two days in between as a washout period and at approximately the same time of day. The participants were asked to eat their habitual lunch no later than 2 h and no sooner than 45 min before test sessions, and to drink only water 1 h before the test session to standardize hunger states. Participants were required to refrain from the use of any heavy make-up around their eyes (e.g. mascara, eyeliner, and eyeshadow) which could affect eye movement measures (<u>Orquin & Holmqvist, 2019</u>). Moreover, the experiment took place during Covid-19 pandemic, participants were asked to reschedule their test session if they presented any symptom related to Covid-19. An alternative goal (“To investigate the role of hunger and satiety on the performance of memory tasks using eye-tracking technology”) was established to distract participants from the actual goal. To this end, participants performed a bogus task in the form of a computerized memory game of moderate difficulty.

Upon arrival, participants were escorted to Room 1. This room was equipped with a vaporizer to disperse the ambient odour (Iscent, Zee-wolde, The Netherlands) where participants were exposed to a non-consciously detectable odour for 10 min. In this room, we first explained the procedure and participants were fitted with a pair of eye-trackers (Tobii eye-trackers wireless glass II, Sweden). The eye-trackers were calibrated using a one-point calibration followed by a five-point validation (<u>Duchowski, 2007</u>). Participants were instructed to keep the eye-tracker until the end of the test session to avoid recalibration. Then, they assessed their general appetite and performed a memory task (#1) which was in line with the alternative goal. After finishing the memory task, they assessed the difficulty of the memory task and their stress level (#1). Subsequently, participants were escorted to Room 2. This room was equipped with a food area where participants could select and consume a snack. Participants stood in front of the food area – ~50 cm from it – while exploring the assortment of different snacks. They were instructed to select only one snack and to consume as much as they could during the break (5 min). After the break, participants were escorted back to Room 1 where they assessed their general appetite after the snack consumption, performed the memory game again (#2), and assessed the difficulty of the memory task and their stress level (#2).

To account for any potential bias, a debriefing questionnaire was

Table 1

| Taste Category | Taste sub-category | Snack                  | Energy per package (local) |
|----------------|--------------------|------------------------|---------------------------|
| Sweet          | Bubble-gum         | Haribo Goldbears       | 257.3                     |
|                |                    | Haribo Peaches         | 266.3                     |
|                |                    | Skittles               | 178.7                     |
| Chocolate      |                    | KitKat                 | 213.7                     |
|                |                    | M&M’s chocolate        | 216                       |
|                |                    | Twix                   | 246.5                     |
| Savoury        | Chips               | Doritos Nacho Cheese   | 219.6                     |
|                |                    | Lay’s Naturel          | 248.0                     |
|                |                    | Lay’s Paprika          | 215.2                     |
| Meat           |                    | BiFi                   | 94.2                      |
|                |                    | Kettle Chips Honey     | 210.4                     |
|                |                    | Barbecue<sup>1</sup>   | 213.2                     |

<sup>1</sup>Kettle Chips Honey Barbecue was not previously piloted. It was included as an alternative to Doritos Bits Honey BBQ which was not anymore available at the time of the main experiment.
completed at the end of the second session. This debriefing questionnaire assessed if participants guessed the aim of the study and if they perceived any odour during the test sessions. Participants were also asked to assess the odours’ attributes (e.g., liking, intensity, familiarity, etc.) and the snacks in their attributes (i.e., liking, familiarity, and sweet and salty/savoury associations). Furthermore, we assessed the sense of smell of the participants. After participants completed the questionnaire, they were debriefed. EyeQuestion® was used to instruct participants and collect the data.

The test procedure is shown in Fig. 1. Only one odour per day was used to avoid odour contamination. After the end of the day, the room was ventilated and the odour was fully removed overnight.

2.4. Measurements

2.4.1. Outcomes of interest

2.4.1.1. Visual attention – eye-tracking metrics. Eye-tracking data retrieved from the Tobii Pro Eye tracking glasses 2 were initially processed by means of Tobii Pro Lab (version 1.145.28180). The eye-tracker collected pictures of the eyes with a sampling rate of 50 Hz, to assess participants’ gaze points based on the position of their eyes. The time of interest for our analyses was established as the time between two events, labelled as ‘start of the snack search’ and ‘end of the snack search’. The ‘start of the snack search’ was defined as the time point where the participant opened the door to Room 2, right before they were exposed to the food area; the ‘end of the snack search’ was established as the moment the participant took the chosen snack. The eye-tracker recordings were analysed by two different researchers in close cooperation. An I-VT-attention-filter and real-world mapping tool (automatic gaze coding) were performed on the raw data during this time of interest. Prior to each test session, a snapshot of the food area was taken and used for the real-world mapping. Areas of Interest (spatial regions where the eye movement measures are quantified; AOI) were defined and labelled in each snapshot as ‘Sweet’ and ‘Savoury’ depending on the taste qualities of the snack products in the food area. AOIs were labelled per taste category (‘Sweet’ and ‘Savoury’). All the videos had a gaze quality above 70%, this cut-off point is in line with other eye-tracking studies (Peng Li et al., 2020); therefore, all of them were included for further analysis. Four parameters – first fixation location and duration, fixation count, and total duration of fixations – were investigated. Location of the first fixation which is the initial orientation. First fixation duration (ms) is defined as the sum of all fixations on an AOI the first time it was viewed before leaving it. Fixation count (#) is the number of fixations recorded within an AOI. Total duration of fixations is defined as the sum of duration of all fixations within an AOI (Orquin & Holmqvist, 2019; Tobii, 2016).

2.4.1.2. Food choice. Congruency of food choice was determined by the snack product chosen relative to the odour category. For example, if participants were exposed to a sweet odour and selected a sweet snack from the food area, this was labelled as congruent (1), otherwise incongruent (0).

2.4.2. Covariates

2.4.2.1. General appetite. General appetite was determined by assessing hunger, fullness, prospective consumption, desire to eat, and thirst on 100 mm VAS; anchored by ‘Not at all’–‘Very’. A ‘General appetite score’ variable was computed with the average of hunger, desire to eat, prospective consumption, and the inverse fullness score (100 – fullness). We used the ‘General appetite score’ computed with the information assessed at the beginning of the test session as a potential covariate.

2.4.2.2. Memory task – as bogus task. The memory tasks were performed online via https://www.improvememory.org/brain-games/memory-games/. Two types of classic memory matching games were used as bogus tasks (‘Easter Memory’ and ‘Memory III’). The memory tasks were randomly assigned to each test session over the blocks. These tasks were moderate in difficulty to be in line with our alternative goal. To prove this, difficulty and stress levels were assessed by rating ‘How difficult was the task you just performed?’ and ‘How stressed do you feel at this moment? on 100 mm VAS anchored from ‘not at all’ to ‘very difficult’/‘stressed’. The difficulty of the memory task was rated as moderate, 50.5 ± SD 19.4 on 100 mm VAS, and consequently the participants were not stressed after the memory task, 36.7 ± SD 19.6 on 100 mm VAS. Moreover, these variables were used as potential covariates in our models as stress might be associated with sweet cravings (Marques Macedo and Diez-Garcia, 2014).

2.4.2.3. Debriefing session

2.4.2.3.1. Goal and odour perception. Participants completed a debriefing questionnaire where they were asked about the goal of the study and whether they had perceived an odour in Room 1 in any of the two test sessions.

Data from odour perception on each test session was classified into four score categories: ‘Not aware of an odour’; ‘Aware of an odour, but odour unidentified’ ‘Aware of an odour, but odour incorrectly identified’ ‘Aware of an odour, and odour correctly identified’ as indicated by (Mors et al., 2018). These scores were added to the statistical models as covariates and results are shown in section 3.4.

2.4.2.3.2. Rating of odours: attributes. Participants received an odourised disposable sheet of paper with the odourant, which was prepared in the same concentration as the exposed odour, to be
evaluated. They assessed the two odours they were exposed to during the test sessions on their liking, intensity, familiarity, intention to eat a product of that odour, mouth-watering sensation, and sweet and salty/savoury associations on a 100 mm VAS scale anchored by ‘Not at all’–‘Very much’. Identification of the odour was assessed by a multiple forced-choice task, (‘Which of the following labels best fits the smelled odour?’). Afterwards, the odour-label correspondence was assessed (‘How well do you think this smell corresponds to ‘specific smell?’’) on a 100 mm VAS scale. After evaluating the first odour, participants waited 30 s before receiving the next odour. The odours’ attributes were used as covariates in the statistical analyses. Odour ratings can be found in the supplementary materials (Table S4).

2.4.2.3.3. Rating of snacks’ attributes. Participants assessed the snack products available in the food area on their liking, familiarity, and sweet and salty/savoury associations on a 100 mm VAS scale. This was done using pictures of the snack products in the food area. The attributes were used as covariates in the statistical analyses and the ratings can be found in the supplementary materials (Table S5).

2.4.2.3.4. Odour identification test – Sniffin’ Sticks. Odour identification scores were assessed using the identification part of the Sniffin’ Sticks test which contains 16 common odours (Burghart Messtechnik GmbH, Wedel, Germany). Participants were presented (by the experimenter) with an disposable sheet of paper where a 2 cm stripe was drawn on with the Sniffin’ Stick, as advised by the current (at the time of writing) Covid-19 recommendations of the German Society for Otolaryngology (<u>https://MediSense, 2020</u>). Participants selected the label which best describes the smelled odour (multiple forced-choice task). Between each odour, participants took a break of 20 s. A correct sum score ≥12 (out of 16) is considered as normosmic (<u>Oleszkiewicz, Schriever, Croy, Hähner, & Hummel, 2019</u>). The mean (and standard deviation) of the odour identification scores was 13.5 ± 1.3. Participants’ scores were added to the statistical analyses as a covariate. It is important to mention that 5 participants obtained an odour identification score of 11 which is slightly below the normosmic cut-off. We decided not to exclude these participants considering that our participants were international people and some of the odours available in the Sniffin’ Stick battery are possibly less well-known in other cultures.

2.5. Statistical analyses

We were interested in the congruency effect, which is dependent on the taste category of the snack products, relative to the type of odours exposed (e.g. sweet AOI was defined as a congruent AOI after exposure to a sweet odour but as an incongruent AOI after savoury odour exposure, and vice versa). Therefore, data were collapsed over the two odours and the six snack products of the same category (i.e. ‘Sweet’ and ‘Savoury’).

Results with a p value lower than 0.05 were considered statistically significant. All statistical analyses were carried out in RStudio (RStudio Team, 2016), and graphs were made using GraphPad Prism 5.0 (GraphPad Prism Software). Most of the analyses consisted of (generalized) linear mixed models, carried out using the lme4 statistical package in R (<u>Gates, Mächler, Bolker, & Walker, 2015</u>), unless indicated otherwise. For these models, participants and test session nested in (13) groups based on participants’ availability (3 groups consisted of 3 participants, 6 of 4 participants and 4 of 5 participants) were evaluated as potential random factors. After checking the random part of each model, all final models only included participants as random effects, as the addition of test session nested in groups was redundant. The best fitting models were selected on the basis of parsimony following a backward approach. Necessity assumptions were checked for each model.

To assess differences in odour and snack characteristics between taste-qualities (sweet and savoury) several mixed models were run. Odour and snack attribute ratings were analysed as the dependent variable, with odour or taste category as fixed effects and participants and evaluation order as potential random effects (e.g. of final model: Liking of the odour ~ odour category + Participant as random effect. These data is shown in Tables S4 and S5 of the supplementary materials.

2.5.1. Primary objective: visual attention and food choice

2.5.1.1. Visual attention – eye-tracking metrics. Two stages of analysis were performed for the first fixation location. In the first stage, a binomial test was performed to assess whether congruent and incongruent snacks have the same probability of being first fixated on. In the second stage, a generalized linear mixed model on the logit scale (glm function) was performed to investigate whether the type of odour exposure (i.e. sweet and savoury) influences the congruency of the first fixation location. Congruency of the first fixation location and odour category were considered as the dependent variable and fixed effects, respectively (Congruency of the first fixation location ~ Odour category + all covariates + Participant as random effect. All potential covariates were initially added to the full model and they were systematically removed if they were non-significant following this order: 1) personal characteristics (gender, age, BMI, DEBQ, BAS, BIS-11 scores, and odour identification score); 2) general appetite score and thirst rating before the memory task #1; 3) stress levels and difficulty of the memory task #1; 4) perception of ambient odour during the test session; 5) odour attribute ratings; 6) snack attribute ratings. In each step, the non-significant covariates corresponding to the evaluated order were removed from the model. Covariates that were significant were included in the (reduced) final model.

Proportions of first fixation duration, fixation count, and total duration of fixations on congruent AOI were computed. Congruent AOI depended on the AOI relative to the odour exposure. Proportion of a parameter (e.g. total duration of fixations) on congruent AOI was calculated by dividing the total duration of fixations on congruent AOI by the sum of total duration of fixations on congruent and incongruent AOI. Furthermore, the data analysis of each parameter followed two stages. In a first stage, we assessed whether the intercept was significantly different from chance level to determine whether odour exposure influences visual attention towards congruent AOI. For this, a new variable ‘Proportion of a parameter on congruent AOI above chance level’ was computed by subtracting 0.5 from the proportion of a parameter on congruent AOI. Linear mixed models (lmer function) were performed with ‘Proportion of a parameter on congruent AOI above chance level’ as the dependent variable (Example of a model: Proportion (of a parameter) on congruency AOI above chance level ~ Odour category + all covariates + Participant as random effect. An intercept significantly different from 0 meant that the odour exposure significantly influences the (in)congruency of visual attention metrics. In a second stage, we assessed the influence of the type of odour category on the congruent AOI. A linear mixed model was performed with the proportion of each parameter on the congruent AOI as the dependent variable and type of odour category as a fixed effect (Proportion (of a parameter) on congruency AOI ~ Odour category + all covariates + Participant as random effect. Systematic removal of the potential covariates was followed as indicated above.

Moreover, exploratory analyses were performed to determine the role of taste category AOI, similar to the two stages described above. Therefore, the proportion of a parameter (e.g. total duration of fixations) on the sweet AOI was calculated by dividing the total duration of fixations on the sweet AOI by the sum of total duration of fixations on sweet and savoury AOI. As mentioned above, for the first stage, ‘Proportion of a parameter on sweet AOI above chance level’ was computed and considered as the dependent variable (Proportion (of a parameter) on sweet AOI above chance level ~ Odour category + all covariates + Participant as random effect. For the second stage, we assessed the influence of the odour category on visual attention towards the sweet AOI, and thus the proportion of each parameter on the sweet AOI was included as the dependent variable (Proportion (of a parameter) on sweet AOI ~ Odour category + all covariates + Participant as random effect.
sweet AOI ~ Odour category + all covariates + Participant as random effect.

2.5.1.2. Food choice. Firstly, a binomial test was performed to test whether congruent vs incongruent food choice (i.e. choice of a savoury snack product after the exposure of a savoury odour was labelled as congruent, otherwise incongruent) have the same probability. Secondly, a generalized linear mixed model was performed to investigate whether the type of odour exposure influences the congruent food choice. Congruency of the chosen category and odour category were considered as the dependent variable and fixed effects, respectively (Congruency of the chosen category ~ Odour category + all covariates + Participant as random effect. Systematic removal of potential covariates was carried out as indicated above.

Similar to the eye-tracker metrics, exploratory analyses were performed to determine the role of the AOI taste category on the two stages described above. Firstly, a binomial test was performed to test whether sweet vs savoury snacks have the same probability of being chosen. Secondly, a generalized linear mixed model was performed to investigate whether the type of odour exposure influences the food choice of sweet snacks. Sweet food choice (sweet snack was chosen/sweet snack was not chosen) and odour category were considered as the dependent variable and fixed effects, respectively (Sweet food choice ~ Odour category + all covariates + Participant as random effect.

2.5.2. Secondary objective: food choice prediction

This objective consisted of two parts: a) Prediction of food choice by snack attributes; b) Correlation of snack attributes to visual attention parameters which could predict food choice. Firstly, two binomial logistic regressions were performed to test the prediction of food choice by snack attributes and visual attention, separately. On the first binomial logistic regression, snack choice (chosen/non-chosen) was entered as the dependent variable and odour category, taste category of the chosen snack, liking, and familiarity of the snack were entered as prediction factors. On the second binomial logistic regression, total duration of fixations (in seconds), fixation count, first fixation duration (in seconds), taste category of the first fixation, congruency of the first fixation with the exposed odour were entered as prediction factors instead of the snack attributes entered in the first binomial logistic regression. Secondly, Pearson correlation analyses were done to test the correlation of snack attributes to visual attention parameters.

3. Results

3.1. Debriefing – odour perception

Two participants reported a link between odours and snack choice, and they were thus removed from the analysis and results as mentioned above. The vast majority of participants believed that the aim of the study was related to the memory task and hunger state. A small percentage (13.2%; 7 out of the 53 participants included for analysis) inferred that the aim was related to food choice; however, they did not make the connection between odour exposure and true study aim. Moreover, participants did not perceive any odour in 87.7% of the test sessions, in 2.8% of the test sessions the odour was perceived but was incorrectly identified. In the remaining 9.4% of the test sessions participants perceived the odour and correctly identified it. This information showed that the odours were non-consciously perceived in the majority of cases.

3.2. Primary objective: visual attention and food choice

3.2.1. Visual attention – eye-tracking metrics

3.2.1.1. First fixation location. The binomial test revealed that participants were more likely to first fixate on congruent snacks (= AOI) after odour exposure compared to incongruent snacks (probability = 0.63, 95% CI = [0.53, 0.7], p = 0.01). This means that sweet products were more often fixated on first after sweet odour exposure; similarly, savoury snacks were more often fixated on first after savoury odour exposure.

The logistic mixed model showed that the probability of congruent first location did not differ between sweet vs savoury odour exposure (sweet odours: 0.63, 95% CI = [0.50,0.76]; savoury odours: 0.63, 95% CI = [0.50,0.77]; ≠ 1 = 0.03; p = 0.86; model included DEBQ External eating score and BIS 11 non-planning score).

3.2.1.2. Duration of the first fixation. In the first stage, the intercept of congruent snacks was significantly lower than 0 (−0.06 ± 0.02; t(52) = −3.0, p = 0.005), meaning that the proportion of duration of first fixation on the snack products was longer for incongruent snacks compared to congruent snacks.

In the second stage, the proportion of duration of the first fixation on congruent snacks tended to be similar across odour categories (Table 2A). Exploratory analyses showed that the intercept of sweet snacks was not significantly different from 0 (0.03 ± 0.02; t(102) = 1.75, p = 0.08) and that the duration of the first fixation on sweet snacks was higher after savoury odour exposure compared to sweet odour exposure (Table 2B).

3.2.1.3. Fixation count. Firstly, the intercept of congruent snacks was not significantly different from 0 for fixation counts (0.02 ± 0.02; t(102) = −1.38, p = 0.17), meaning that after odour exposure, the number of fixations on congruent snacks was similar to the number of fixations on incongruent snacks. Secondly, participants fixated more frequently on congruent snacks after exposure to sweet odours compared to savoury odours (Table 2A). Exploratory analyses showed that the intercept of sweet snacks was significantly higher than 0 (0.06 ± 0.02; t(52) = 3.67, p = 0.001) and that participants fixated more frequently on sweet snacks after sweet odour exposure compared to savoury odour exposure (Table 2B).

3.2.1.4. Fixation duration. In the first stage, the intercept on congruent snacks was not significantly different from 0 (0.02 ± 0.02; t(102) = 0.73, p = 0.47). This means that the time fixated on congruent snacks was similar to the time fixated on incongruent snacks. In the second stage, a linear mixed model with proportion of total fixation duration on congruent snacks showed that participants fixated for a longer time on

| Outcome measure | Odour category | Statistical information |
|-----------------|---------------|------------------------|
| A) Congruent snacks |               |                        |
| Proportion of duration of first fixation | 0.47 ± 0.03 | F(1,51) = 3.7, p = 0.06 |
| Proportion of fixation count | 0.57 ± 0.02 | F(1,65) = 10.20, p < 0.002 |
| Proportion of fixation duration | 0.60 ± 0.03 | F(1,51) = 19.93, p < 0.0001 |
| B) Exploratory analyses – Sweet snacks |               |                        |
| Proportion of duration of first fixation | 0.48 ± 0.03 | F(1,54) = 7.67, p = 0.01 |
| Proportion of fixation count | 0.59 ± 0.02 | F(1,50) = 4.10, p = 0.048 |
| Proportion of fixation duration | 0.60 ± 0.03 | F(1,51) = 0.87, p = 0.35 |

Covariates included in the mixed models: *No covariates; *Familiarity and liking of the congruent snack products and familiarity of the odour; *Odour-label association; Stress after the first memory task.
congruent snacks after the exposure of sweet odours compared to savoury odours (Table 2A).

Exploratory analyses showed that the intercept on sweet snacks was significantly higher than 0 (0.09 ± 0.02; t(52) = 3.9, p = 0.0003) and the proportion of total fixation duration on sweet snacks revealed no significant difference among odour categories (Table 2B). These four models indicate that participants fixated on sweet snack products for a longer time, regardless of the type of odour exposure.

3.2.2. Food choice

Firstly, a binomial test revealed that congruent and incongruent snacks were equally frequently chosen (probability = 0.53, 95% CI = [0.43, 0.63], p = 0.62). Secondly, the logistic mixed model showed that participants more frequently chose congruent snacks after a sweet odour compared to a savoury odour ($\chi^2(1) = 15.71; p < 0.0001$; no covariate was included in the final model; Fig. 2A). Exploratory analyses showed that participants were more likely to choose sweet snacks compared to savoury snacks (probability = 0.63, 95% CI = [0.53, 0.72], p = 0.01) and that sweet snacks were chosen with similar frequency regardless of the odour exposure ($\chi^2(1) = 0.35; p = 0.55$; mixed model included familiarity of the chosen snack products; Fig. 2B).

3.3. Secondary objective: food choice prediction

The first prediction model indicates that a snack has a 2 and 6% higher chance of being chosen (vs not being chosen) for every unit change in liking and familiarity of the snack, respectively (Table 3A). Moreover, the second prediction model indicates that a snack has a 150% higher chance of being chosen (vs not being chosen) for every second that a snack is fixated upon, given that all the other variables remain constant. However, the chance of a snack being chosen (vs not being chosen) decreases 18% for every unit change in fixation count (Table 3B).

Moreover, ‘Liking of the snack’ was not significantly correlated to the visual attention parameters (‘Total fixation duration’ r(179) = 0.06, p = 0.43; ‘Fixation count’ r(179) = 0.06, p = 0.42) while a low significant positive correlation was found between ‘Familiarity of the snack’ and the visual attention parameters (‘Total fixation duration’ r(179) = 0.17, p = 0.02; ‘Fixation count’ r(179) = 0.16, p = 0.04). Fig. 3 illustrates the food choice prediction model.

4. Discussion and conclusion

4.1. Discussion

The aim of the current study was to determine the impact of odour priming on congruent visual attention and snack choice. Further, we aimed to determine the relationship between visual attention and food choice. Our results show that, overall, sweet snacks were chosen more often compared to savoury snacks, regardless of the type of odour exposure. Moreover, sweet snack products were more frequently and longer fixated on. Conversely, the first fixation location was congruent to the odour exposure (i.e., participants first fixated on sweet snack products after being exposed to sweet odours, and vice versa); however, participants spent more time gazing at incongruent snack products during the first fixation. In addition, our results show that food choice can be predicted by total fixation time, fixation count, and liking and familiarity of the snack products, but not by odour exposure, first fixation location, nor duration.

According to Russo and Leclerc, (food) choice processes consist of different stages: initial orientation (and screening), evaluation, and verification (Russo & Leclerc, 1994). This segmentation of the choice

### Table 3

| Predictor factors* | β   | SE  | Wald  | p-value | $e^5$ – odd ratio (mean (95% CI)) |
|--------------------|-----|-----|-------|---------|----------------------------------|
| a) Prediction of food choice by snack attributes |    |     |       |         |                                   |
| Intercept          | −5.57 | 1.17 |       | 1.02 (1.00, 2.53) |
| Liking of the snack | 0.02  | 0.01 | 4.03  | 0.04    | 2.48 (1.73, 3.55) |
| Familiarity of the snack | 0.05  | 0.01 | 19.35 | <0.0001 | 1.06 (1.03, 1.84) |
| b) Prediction of food choice by visual attention |    |     |       |         |                                   |
| Intercept          | −1.43 | 0.36 |       |         |                                   |
| Total fixation     | 0.91  | 0.18 | 24.41 | <0.0001 | 2.48 (1.73, 3.55) |
| Fixation count     | −0.20 | 0.06 | 10.71 | 0.001   | 0.82 (0.73, 0.92) |

*Significant factors.

![Fig. 2. Proportion of congruent (A) and sweet (B) food choice after sweet and savoury odour exposure. Values are expressed as mean and standard error.](image-url)
process may result in distinct eye-movements during the different stages (\textless u\textgreater Glaholt & Reingold, 2011 \textless u\textgreater; Russo & Leclerc, 1994). Therefore, we investigated how visual attention evolves over these different stages. The first fixation in a food-choice paradigm is related to the orientation stage. This stage may occur implicitly, without conscious control, and is considered to be more intuitive and spontaneous stage (Betsch et al., 2003, <u>2006</u>; Russo & Leclerc, 1994). The first fixation location in this study was dominated towards snacks that were congruent with the odour exposure. We infer that this congruency effect is the result of implicit odour priming. During the orientation and screening stage an overview of the available products is acquired (Russo & Leclerc, 1994). Some of the products gazed upon during this first stage are never fixated on again, showing eliminations before moving to the following stages (Russo & Leclerc, 1994). Our results showed that incongruent snacks were fixated on longer than congruent snacks during this first fixation, suggesting an exploration of the available products and certain (initial) eliminations. Next, cognitive processes are involved in this first fixation, suggesting an exploration of the available products following stages (Russo & Leclerc, 1994). We infer that this priming may be vital to successfully steer the final decision towards a congruent product, but not beyond that stage towards snack choice. The latter congruent odour, light, and sound exposure showed no effects on visit frequency or sales, suggesting that any sensory priming effect may be small (\textless u\textgreater de Wijk, Maaskant, Kremer, Holthuijzen, & Stijnen, 2018 <u>2018</u>). The use of immersive rooms or virtual reality applications where participants can more vividly experience a real-life food setting (e.g. supermarket, restaurant, or main street), and where researchers can control the priming cues, could offer more insight into the impact of odour priming on food choice.

It is worth discussing the discrepancy between results from previous studies to understand the influence of odour priming on food choice or intake. Studies where odour priming did not impact food choice involved neutral (Mors et al., 2018) or macronutrient-related odours (\textless u\textgreater Morquecho-Campos et al., 2021 <u>2021</u>). However, studies where odour priming did impact food choice and intake involved sweet-fruity (\textless u\textgreater Gaillet-Torrent et al., 2014 <u>2014</u>; Gaillet et al., 2013), sweet-fatty (\textless u\textgreater Chambaron et al., 2015 <u>2015</u>), or high-calorie related odours (\textless u\textgreater Proserpio, de Graaf, Laureati, Paglierini, & Boesveldt, 2017 <u>2017</u>). This may imply that ‘indulgent’ odours may influence congruent food choice and intake, while other odours do not. The current study involved odours that signalled sweet and savoury taste qualities. If we had merely looked at the impact of sweet odour exposure, our results would point towards a congruent influence of odour exposure on fixation count, fixation duration, and food choice. However, without a no-odour control condition, we cannot infer that sweet odour exposure increased visual attention towards sweet foods. Nevertheless, there are studies that found significant differences between sweet odours and no-odour conditions, indicating that sweet odour priming might elicit eating responses (\textless u\textgreater Chambaron et al., 2015 <u>2015</u>; Gaillet-Torrent et al., 2014; Gaillet et al., 2013). In contrast, a study from de Wijk & Zijlstra did not find a congruent food choice effect in response to vanilla odour (de Wijk & Zijlstra, 2012). In the same study they did find a congruent food choice effect after the exposure to citrus odour. This can however be explained by the fact that citrus odour might elicit sweet taste associations, thereby indicating that sweet odour priming indeed leads to eating responses. We therefore suggest that the type of odour used (sweet/savoury) may signal specific information and activate (or not) specific wanting process. Sweet food may convey more hedonic properties suggesting a stronger reward activation (Ma, Ratnasabapathy, & Gardiner, 2017; Ventura, Santander, Torres, & Contreras, 2014, for reviews), while savoury food may be associated with protein intake and homeostasis (\textless u\textgreater Griffeno-Roese et al., 2010 <u>2010</u>; \textless u\textgreater O’Doherty, Rolls, Francis, Bowtell, & McGlone, 2001 <u>2001</u>; Simpson & Raubenheimer, 2005). Therefore, the indulgent and reward information transmitted by the (visual) encounter with sweet food might be stronger than a general odour priming effect.

Finally, one limitation that should be mentioned which could have increased the choice of and attention to sweet snacks, was the lack of variety in the savoury snacks. Most of the savoury snacks consisted of chips (5 out 6 snacks); while the sweet snacks were evenly distributed over two categories (3 chocolates and 3 wine gums). The snack options of the taste sub-category meat were limited, therefore we used chips with meat flavours. Even though, the savoury food items were rated as less familiar compared to the sweet ones, familiarity of the snacks did not contribute to the majority of our models. Another potential limitation of this study to capture impulsive behaviour was the unrestricted time for selecting the snack. The participants were allowed to freely choose and consuming a congruent food product. Although, people can identify with the situation of buying an unplanned freshly baked muffin while walking in the supermarket or main street and smelling the chocolate odour, several studies have failed to replicate this effect in a laboratory setting (\textless u\textgreater Morquecho-Campos et al., 2021 <u>2021</u>; Mors et al., 2018). By using the wearable eye-tracker, we intended to gain insights to human food choice processes in a naturalistic environment and as they occur in time. However, participants clearly came to the laboratory to participate in a study; therefore, the laboratory setting ambiance was still present. A real-life supermarket study that involved congruent odour, light, and sound exposure showed no effects on visit frequency or sales, suggesting that any sensory priming effect may be small (\textless u\textgreater de Wijk, Maaskant, Kremer, Holthuijzen, & Stijnen, 2018 <u>2018</u>).
explore the area, without any further indication. Automatic and more impulsive responses are triggered during short and limited time intervals, in an effortless manner, and may enhance priming effects (Hermans, Houwer, & Eelen, 2001; Manippa et al., 2019). Moreover, it is noteworthy mentioning that the odour attribute assessment was performed in a different condition compared to actual odour exposure (actively smelling by means of disposable sheet instead of passively smelling by means of vaporizers) which might have altered the perceived odour quality and intensity and therefore the odour attributes (i.e., liking, familiarity, etc.). Ideally, this assessment should have been done in the same condition as the odour exposure of interest (i.e., ambient odour exposure).

As our secondary objective, we aimed to predict food choice based on snack attributes and visual attention. Our results showed that the snack attributes evaluated are not strong food choice predictors. Also, these attributes (liking and familiariry of the snacks, respectively) are not significantly or poorly correlated to the visual attention parameters. This lack of correlation might indicate that these self-reported measures are not a good reflection of the decision-making process. Moreover, our results showed that participants spent longer looking at options they chose compared to options they did not choose, suggesting longer examinations and verification of the ultimate choice. This is in line with previous studies that showed that more time is spent fixating on chosen options compared to not chosen options (Pieters & Warlop, 1999; Schotter et al., 2010); however, research on food choice has some contrary results (Armel et al., 2008; Manippa et al., 2019; van der Laan et al., 2015; Wang et al., 2018; Werthmann et al., 2011). Our second prediction model also suggests that total fixation time positively predicts the food choice, while number of fixations decreases the chance of products to be selected. An increase in the number of fixations might be related to a higher working memory load and is considered to reflect decision difficulty (Krajbich, Lu, Camerer, & Rangel, 2012; Orquin & Mueller Loose, 2013). Finally, first fixation location and first fixation duration did not significantly contribute to our second prediction model which is in line with van der Laan and collaborators who showed that first fixation did not influence choice (van der Laan et al., 2015). However, Werthmann et al. showed that the direction of the first gaze, and not the total fixation time, may predict consumption (Werthmann et al., 2011). Considerably more work will need to be done, in particular in the food domain, to determine the relationship between visual attention and food choice.

Finally, even though we assessed olfactory function of the participants by means of the Sniffin Sticks, we did not assess their detection threshold for the odorants used in the study. As there are individual differences in odour perception (Keller, Zhuang, Chi, Vossnall, & Matsunami, 2007), this could mean that some participants were not able to perceive the low concentrated ambient odour, resulting in an absent effect of odour priming. However, as the Sniffin Sticks is a widely validated screening tool to classify people into normosmia, hyposmia and anosmia (Oleszkiewicz et al., 2019), we deem it unlikely that our participants were not able to perceive the odours.

5. Conclusion

Odour priming did congruently influence the first fixation location, which is related to non-conscious control. However, sweet snacks were fixated on more frequently and for a longer period of time, and were chosen most often, regardless of the type of odour. The type of odour may signal different reward information (sweet vs savoury taste quality) and may thus influence (or not) eating behaviour. Future research using the simultaneous delivery of multisensory cues, more realistic settings and implicit measures is needed to further understand the role of odours on eating behaviour.

Declarations of interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.appet.2021.105772.

Author contributions

Paulina Morquecho-Campos: Conceptualization, Methodology, Resources, Investigation, Formal analysis, and Writing – original draft. Ina M. Hellmich and Elske Zwart: Methodology, Investigation, Data curation, Formal analysis, Writing – review & editing. Kees de Graaf: Methodology and Supervision. Sanne Boesveldt: Conceptualization, Methodology, Writing – review & editing, and Supervision.

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