Appetite 123 (2018) 7–13

Contents lists available at ScienceDirect

Appetite

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

Detection thresholds for four different fatty stimuli are associated with increased dietary intake of processed high-caloric food

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A R T I C L E I N F O

Article history:
Received 5 August 2017
Received in revised form
18 November 2017
Accepted 1 December 2017

Keywords:
Fat taste
Fat perception
BMI
Diet

A B S T R A C T

BMI-specific differences in food choice and energy intake have been suggested to modulate taste perception. However, associations between body composition and fat taste sensitivity are controversial. The objective of this study was to examine the association between body composition, dietary intake and detection thresholds of four fatty stimuli (oleic acid, paraffin oil, canola oil, and canola oil spiked with oleic acid) that could be perceived via gustatory and/or textural cues. In 30 participants, fat detection thresholds were determined in a repeated measurements design over twelve days. Weight status was examined by measuring the participants' BMI, waist circumference and waist-to-hip ratio. The habitual food intake was assessed via several questionnaires and twelve, non-consecutive 24-hour food diaries. In this study, a negative correlation was found between fat detection thresholds and the intake of food rich in vitamins and fibre. Moreover, a positive correlation was identified between the intake of high-fat food and fat detection thresholds. No differences in fat detection thresholds were observed due to variations in BMI or waist-to-hip ratio. These findings indicate that a regular intake of fatty foods might decrease an individuals' perceptual response to fats which might lead to excess fat intake on the long term.

1. Introduction

Dietary fat is known to be a flavor carrier, to positively affect the texture of food and to increase the palatability and consumption of a meal (Drewnowski, 1997; Wolfram et al., 2015). However, without control of total energy intake, an elevated intake of the energy-dense dietary fat may increase the risk for the development of overweightness and obesity, especially since the liking for fat was found to be a major risk factor for obesity (Lampure et al., 2016). Generally, the fat content of food is noticed through textural attributes such as creaminess and viscosity (Sonne, Busch-Stockfisch, Weiss & Hinrichs, 2014; Rolls, 2015). However, several studies have shown that free fatty acids (FFAs) can be tasted in the oral cavity when visual, olfactory and textural cues are masked (Chale-Rush, Burgess & Mattes, 2007; Mattes, 2009a, 2009b; Stewart et al., 2010; Stewart, Newman & Keast, 2011a). FFAs are the digestive break-down product of triacylglycerols (TAGs) that can be hydrolysed by human lipases and can interact with receptors located on taste buds, thereby evoking a pungent, rancid taste in the mouth to prevent the consumption of spoiled foods (Running, Hayes & Ziegler, 2017). Humans have been found to differ intra- and inter-individually in their sensitivity for these FFAs which can be affected by various factors (Running, Mattes & Tucker, 2013; Heinze, Preissl, Fritsche & Frank, 2015). The discussion on the

Abbreviations: 3-AFC, 3-alternative forced choice method; CanO, Canola Oil; CanOOleA, Canola Oil spiked with Oleic Acid; CD36, Cluster of differentiation 36; EDTA, Ethylenediaminetetraacetic acid; FFA, free fatty acid; FFQ, Food Frequency Questionnaire; GPR120, G-protein coupled receptor 120; OleA, Oleic Acid; ParO, Paraffin Oil; TAG, triacylglycerol; TFEQ, Three factor eating questionnaire; VAS, visual analogue scales; WHR, waist-to-hip ratio.

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https://doi.org/10.1016/j.appet.2017.12.003
0195-6663/

association between BMI and fat sensitivity is currently controversial. While some studies observed increased fat detection thresholds (less sensitivity for low concentrations) in participants with increased BMI (Stewart et al., 2010; Stewart et al., 2011a; Stewart et al., 2011b; Stewart & Keast, 2012; Tucker, Edlinger Craig & Mattes, 2014; Daoudi et al., 2015; Sayed et al., 2015), other studies did not find BMI-specific differences in their study populations (Alexy et al., 2010; Alexy et al., 2011; Mattes, 2011; Tucker, Laguna, Quinn & Mattes, 2013; Chevrot et al., 2014). A recent meta-analysis did not indicate that BMI was significantly associated with fat taste sensitivity (Tucker et al., 2017).

Moreover, it was observed that the fat content in the diet could affect fat detection thresholds. Study participants that were able to detect lower concentrations of the FFA oleic acid consumed significantly lower amounts of energy and fat compared to participants that were less sensitive for oleic acid (Stewart et al., 2010; Stewart et al., 2011a). Furthermore, it was shown that dietary changes could also have an impact on fat sensitivity. Several studies have shown that reducing the fat content in the diet resulted in improved fat sensitivity (Mattes, 1993; Stewart & Keast, 2012; Newman, Bolhuis, Torres & Keast, 2016a). However, BMI-specific differences on the effects of dietary changes were observed. A low-fat diet over four weeks resulted in significantly lower oleic acid detection thresholds compared to baseline measurements in normal weight, overweight, and obese participants. In contrast, compared to baseline, a four week high-fat diet led to increased detection thresholds in lean participants but no significant differences in overweight and obese participants (Stewart & Keast, 2012). Therefore, it was assumed that overweight and obese participants may have already adapted to a high-fat exposure in their habitual diet (Stewart & Keast, 2012).

A recent review by Cox, Hendrie, and Carty (2016) investigated whether normal and overweight/obese individuals differ in their sensitivity, hedonics and preference for basic tastes and fatty foods. They reported that decreased sensitivity and increased preference and liking for fat was associated with increased BMI. Nonetheless, a demand for future studies examining different adiposity measurements, the actual dietary intake and taste sensitivity and perception was acknowledged. The aim of the current study was to assess associations between body composition, food intake and perceptual recognition for four fatty stimuli. These four stimuli (oleic acid (a FFA), paraffin oil (mixture of hydrocarbons), canola oil (TAG-rich) and canola oil spiked with oleic acid (rich in TAGs and FFAs)) differ in their chemical composition and can be perceived orally via gustatory or textural cues. To investigate associations between body composition and perceptual recognition of fats, anthropometric measurements (BMI, waist and hip circumference, waist-to-hip-ratio (WHR)) were determined. To study the effect of dietary behavior, participants were required to complete several eating behavior related questionnaires and to record their food intake over 24-hours on twelve non-consecutive days. It was expected that a higher fat content in the diet would be associated with an attenuated perceptual recognition of fat (higher detection thresholds).

2. Experimental methods

2.1. Study outline

The aim of this study was to examine whether body composition and habitual food intake were associated with the perceptual recognition of different fatty stimuli. Detection thresholds for four fatty stimuli (oleic acid, paraffin oil, canola oil, canola oil + oleic acid) were determined in three non-consecutive laboratory sessions per stimuli. Hence, participants were required to attend twelve sessions in total at the Deakin University Centre for Advanced Sensory Science. For each session, participants were required to fast overnight and to attend the laboratory at the same time in the morning for each of the twelve sessions. There was no strict time in which all sessions had to be completed. The maximum time taken to complete all sessions was ten weeks.

2.2. Participants

Individuals aged between 18 and 55 years, not pregnant or lactating, suffering from lactose-intolerance or impaired smell or taste functions were eligible for participation. Based on the central limits theorem, a sample size of $N = 30$ was justified. The 30 participants included were recruited from Deakin University, Burwood, Victoria, Australia and provided written informed consent prior to participating in the study. The study was approved by the Deakin University Human Ethics Advisory Group (HEAG-H 89_2016) and complied with the principles laid down in the Declaration of Helsinki.

2.3. Determination of fat detection thresholds

To expand the knowledge of human fat sensitivity, four fatty stimuli that could be detected via gustatory and/or textural cues were chosen. The FFA oleic acid was chosen based on an established procedure (Haryono, Sprajcer & Keast, 2014) and to control for fat sensitivity associated with gustatory cues. Paraffin oil (mixture of hydrocarbons) was included to control for fat perception based on textural cues. Because paraffin oil does not contain FFAs nor TAGs, fatty taste sensations evoked by FFAs can be ruled out. In contrast, canola oil (TAGs-rich) can be perceived by two possible mechanisms. Firstly, it can be perceived by textural cues due to the high amount of TAGs that affect viscosity (Valeri & Meirelles, 1997) and secondly by the gustatory sensations due to the low concentration of FFAs that is naturally present in oils (1–2%) (Gunstone & Norris, 1983; Koriyama, Wongso, Watanabe & Abe, 2002). Additionally, the amount of FFAs in canola oil can be increased by lingual lipases that hydrolyse TAGs into glycerol and FFAs (Pepino, Love-Gregory, Klein & Abumrad, 2012; Voigt et al., 2014). Furthermore, canola oil spiked with oleic acid was included as mixed stimulus that could be perceived via gustatory and textural cues. By using increasing concentrations of canola oil spiked with a fixed amount of oleic acid (3.80 mM, based on mean detection thresholds of previous studies (Stewart et al., 2010; Stewart & Keast, 2012; Newman & Keast, 2013)) it was expected that some participants would detect this stimulus due to gustatory sensations evoked by the addition of oleic acid, whereas other participants would refer to textural cues due to the TAG-rich canola oil.

Fat detection thresholds were determined using a 3-alternative forced choice test (3-AFC), based on the protocol of Haryono et al. (2014). Concentrations for oleic acid (Sigma-Aldrich Chemie GmbH, Steinheim, Germany) were also taken from this protocol, whereas the concentrations for paraffin oil (Sanofi Consumer Healthcare, Virginia, Queensland, Australia), canola oil (Coles, Hawthorn East, Victoria, Australia), and canola oil + oleic acid were based on pilot studies using 0.15 log steps with a starting point of 1.00% fat in the samples. Concentration steps 1 and 13 were extrapolated to ensure that all participants could perceive the stimuli in the milk-based samples.

All samples were freshly prepared on the morning of each testing day. For each of the four stimuli, a base solution containing the fat in an emulsified form was prepared by adding 5% w/v gum Arabic (Tic Gums, Parramalta, New South Wales, Australia) to ultra-high-temperature pasteurized non-fat milk (Devondale, Southbank, Victoria, Australia). When oleic acid or canola oil + oleic acid