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Considering healthiness promotes healthier choices but modulates medial prefrontal cortex differently in children compared with adults

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ABSTRACT

Childhood obesity is a rising problem worldwide mainly caused by overconsumption, which is driven by food choices. In adults, food choices are based on a value signal encoded in the medial prefrontal cortex (mPFC). This signal is modulated by the dorsolateral prefrontal cortex (dlPFC), which is involved in self-control.

We aimed to examine the neural correlates of food choice in children, and how considering healthiness affects neural activity and choice behavior.

24 children and 28 adults performed a food choice task while being scanned with fMRI and provided health and taste ratings of the foods afterwards. During the choice task participants considered either the healthiness or tastiness of the food or chose naturally.

Health rating was a positive predictor of choice in adults, but a negative predictor in children. Children had weaker dlPFC activation than adults during yes vs. no independent of health or taste condition. Both children and adults made healthier choices when considering healthiness. Taste rating modulated mPFC activation in both children and adults. When considering the healthiness, health rating positively modulated mPFC activation in adults, but negatively in children. Considering the healthiness increased connectivity between dlPFC and mPFC in adults, but not in children.

In conclusion, considering healthiness can promote healthier choices in both children and adults, but is accompanied by an opposing pattern of brain activation in the mPFC. Since the absolute number of healthy choices remained lower in children, this suggests that children may not yet be geared to modify their choices away from their natural tendency to choose unhealthy tasty foods. Thus, this study suggests that it may be promising to develop interventions that increase children's preference for healthy food, for example by increasing the habitual consumption of healthy foods from a young age.

1. Introduction

Childhood obesity is a rising problem almost everywhere in the world (Ng et al., 2014). Compared to normal weight children, overweight children have a much higher chance to develop into overweight adults (Styne, 2001). Weight gain, and thus overweight and obesity, is mainly caused by overconsumption (Blundell and Cooling, 2000; Westerterp and Speakman, 2008), which is driven by food choices (Smeets et al., 2012). Examining the neural correlates of healthy and unhealthy food choices in children may elucidate the mechanisms underlying maladaptive eating behavior in children. When decisions such as food choices are made, the different attributes of choice options (e.g., taste, healthiness, portion size, and packaging) are valued, weighed and integrated into a single value for each option (Bettman et al., 1998; Rangel, 2013). In adults, neuroimaging studies have consistently shown that that value is encoded in the ventromedial prefrontal cortex (vmPFC) (Chib et al., 2009; Hare et al., 2009, 2011, 2008; Kang et al., 2011; Lim et al., 2011; Litt et al., 2011; Plassmann et al., 2010). During food choice, the tastiness of foods contributes to the valuation signal in the vmPFC (Hare et al., 2011). Healthiness is included in the valuation signal as well, when individuals with a health goal make healthy choices (Hare et al., 2009) or when people without an explicit health goal consider the

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healthiness of foods during their choices (Hare et al., 2011). When asked to consider healthiness, the vmPFC signal is modulated by the dorsolateral prefrontal cortex (dlPFC) and participants make healthier choices (Hare et al., 2011). There are several reasons why it may be harder for children than for adults to choose healthy foods. First, choosing a healthy food over a tasty unhealthy food requires self-control, which is not fully developed yet in children and adolescents. This is apparent from both response inhibition and choice impulsivity tasks such as delay discounting tasks (Casey, 2015). Second, children may be more susceptible to food cues than adults (van Meer et al., 2015; van Meer et al., 2016b). For example, in an eye-tracking study adults were initially strongly attracted by unhealthy foods, but shifted their attention from unhealthy to healthy foods, while children attended more to unhealthy foods and did not shift their attention away (Junghans et al., 2015). Furthermore, children showed more craving than adults both in behavioral and neuroimaging measures in a regulation of craving task and older age predicted less craving and enhanced lateral prefrontal recruitment (Silvers et al., 2014). The underlying cause of these differences between children and adults is that the brain of children has not yet matured. Notably, not all brain areas mature at the same rate; relatively greater developmental changes have been reported in the prefrontal cortex (PFC) (Booth et al., 2003). The PFC is involved in various aspects of cognitive processing including valuation (vmPFC) and response inhibition (lateral PFC). In children, the neural correlates of (healthy) food choice are largely unknown (van Meer et al., 2016a), only one study examined the neural correlates of healthy food choice in children (Lim et al., 2016). When children chose foods for themselves the vmPFC value signal encoded only the taste of the foods. However, when children indicated the foods their mothers would pick for them, their projected mother's choice correlated positively with dlPFC activation and the children chose healthier foods. Since an adult group was not included, no direct comparison between children and adults could be made. It remains unknown whether children can modify their own choice behavior and to what extent this is associated with changes in vmPFC and dlPFC activation. Children may not be able to utilize the dlPFC-vmPFC network to achieve healthier choice behavior as successfully as adults do, because of the relative immaturity of the PFC. Therefore, we aimed to examine the neural correlates of healthy food choice in children and how these differ from those in adults. Additionally, we aimed to determine whether health cues can modify choice behavior in children, and if so, how this affects vmPFC and dlPFC activation.

2. Methods

2.1. Participants

Children between 10 and 12 years old and their gender-matched parents were included in this study. Both normal weight and overweight children and adults were included (BMI criteria children: standardized BMI score (SDS BMI) between −1.1 and 2.5; BMI criteria adults: between 18.5 and 37.5). Exclusion criteria were: in addition to the general MRI exclusion criteria, being left-handed, having an eating disorder, having a food allergy, following a diet (medically prescribed or for weight-loss), and having a gastro-intestinal disorder or a history of surgical or medical events that might significantly affect the study outcome. Additionally, regular smokers (>1 cigarette per day) or participants with a historical or current alcohol consumption of >28 units per week were excluded. Exclusion criteria were the same for children and adults. Thirty-two children and their thirty-two gender-matched parents enrolled in the study. Twelve participants were excluded from analysis, due to excessive head movement (two children) or because of a lack of variety in the choices in the food choice task (four adults and six children; see section 'Food choice fMRI task'). Twenty-four children and twenty-eight adults were included in the final analyses (for characteristics see Table 1).

Table 1
Demographic variables per group.

	Children (n = 24, 17F)			Adults (n = 28, 19F)		
	Mean	Range	SD	Mean	Range	SD
Age	10.8	10–12	0.76	43.9	32–52	3.80
(SDS) BMI[a]	0.30	−0.92–2.32	0.84	25.1	19.4–36.9	3.93
Tanner stage[b]	1.75	1–3	0.74			
Highest level of education				4.57	2–6	1.20

[a] BMI in kg/m^2 is reported for adults, BMI standard deviation score (SDS BMI) is reported for children.

[b] There was no significant difference in Tanner stage between girls and boys $t(22) = -1.49$, $p = 0.89$.

2.2. Procedure

The procedures followed were in accordance with the ethical standards of the University Medical Center Utrecht and were approved by the Utrecht Medical Center Medical Ethical Committee. The study consisted of two sessions. During the first session, children were familiarized with the scan protocol and the food choice task using a mock scanner. Using a mock scanner to train children decreases anxiety and increases data quality (Bie et al., 2010; Durston et al., 2009). Participants were instructed to refrain from eating and drinking (except water) for 2 h prior to the second session (the scan day). Parents and children were always scanned on the same day, and children were scanned first. Examinations usually took place in the morning (between 08:00–12:00 h). 3 child-parent pairs were scanned in the afternoon. Participants' height and weight were measured. After that they performed a food choice and a food viewing task while being scanned. We here focus on the food choice task, results of the food viewing task have been published elsewhere (van Meer et al., 2016b). Afterwards, participants were asked to rate the foods from the food choice task (n = 150) on their healthiness and tastiness on a five point scale in a computerized rating task. Children provided self-reported Tanner stages by indicating the best matching drawing showing external primary and secondary sex characteristics from a set of five (see Table 1).

2.3. Food choice fMRI task

This experiment used a food choice task adapted from Hare et al., (2011) (Fig. 1). In this task participants are shown a picture of a food item for 2 s and are given 2 s to indicate whether they want to eat the food after the experiment by pressing a left (yes) or right (no) button with their right thumb, as van der Laan et al. (2014). 150 trials were presented. A random trial was selected as the trial that counted for real. Trials were separated by a variable inter-trial interval between 1.4 and 4.2 s. The sequence of trials was optimized and counterbalanced using the Optseq2 algorithm (https://surfer.nmr.mgh.harvard.edu/optseq/), which provides temporal jitter to increase signal discriminability (Dale, 1999). Participants made choices in three different attention conditions. In the health condition they were asked to consider the healthiness of the food, in the taste condition they were asked to consider the taste of the food and in the natural condition they were asked to consider the food as a whole and choose naturally. Critically, the instructions emphasized that subjects should always choose what they preferred, regardless of the condition. The attention condition was kept constant for 10 trials at a time, and the beginning of a new condition was announced with a 5 s instruction screen. After receiving task instructions, subjects completed 150 trials in the scanner; 50 in each condition. Each food was shown only once and the order of conditions was fully randomized for each subject. If subjects said either yes to less than 25% of the items or no to less than 25% of the items, their data were excluded from the analyses (n = 10, 6 children). The excluded individuals did not differ from the included group in (SDS) BMI or age. Stimuli were presented on a screen which was viewed via a mirror on the head coil with use of the PRESENTATION software (Neurobehavioral