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The role of neural impulse control mechanisms for dietary success in obesity

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ABSTRACT

Deficits in impulse control are discussed as key mechanisms for major worldwide health problems such as drug addiction and obesity. For example, obese subjects have difficulty controlling their impulses to overeat when faced with food items. Here, we investigated the role of neural impulse control mechanisms for dietary success in middle-aged obese subjects. Specifically, we used a food-specific delayed gratification paradigm and functional magnetic resonance imaging to measure eating-related impulse-control in middle-aged obese subjects just before they underwent a twelve-week low calorie diet. As expected, we found that subjects with higher behavioral impulse control subsequently lost more weight. Furthermore, brain activity before the diet in VMPFC and DLPFC correlates with subsequent weight loss. Additionally, a connectivity analysis revealed that stronger functional connectivity between these regions is associated with better dietary success and impulse control. Thus, the degree to which subjects can control their eating impulses might depend on the interplay between control regions (DLPFC) and regions signaling the reward of food (VMPFC). This could potentially constitute a general mechanism that also extends to other disorders such as drug addiction or alcohol abuse.

Introduction

Obesity is a major and increasing worldwide health problem due to its high prevalence and severe medical consequences (Bray, 2004). A variety of factors in the development and maintenance of obesity are currently discussed, including psychological (e.g., Ng & Jeffery, 2003; Rodin et al., 1989; Rothemund et al., 2007; Torres and Nowson, 2007; Weygandt et al., 2012), behavioral (e.g., Bellisle et al., 2004; Hays and Roberts, 2008), genetic (e.g., Dina et al., 2007; Frayling et al., 2007), and endocrinological (e.g., Ahima, 2008; Farooqi et al., 2007; Klok et al., 2007; Page et al., 2011; Rosenbaum et al., 2008). Within the latter framework, also (insufficient) cerebral insulin suppression during stressful events is discussed, a topic especially referred to in the literature on the 'selfish-brain theory' (cf. Peters, 2011). Among psychological factors, impaired impulse control is believed to play an important role for obesity (e.g., Batterink et al., 2010; Kishinevsky et al., 2012; Masheb and Grilo, 2002; McGuire et al., 2001; Nijs et al., 2010; Weller et al., 2008) as well as for other major health problems, such as drug addiction (e.g., Barrós-Loscertales et al., 2011; Goldstein et al., 2007; Volkow et al., 2004) and alcohol abuse (e.g., Li et al., 2009). The association of obesity and impulse control has been tested in behavioral studies that found that impulse control measured with delay discounting (DD) paradigms or questionnaires is negatively associated with body weight (Masheb and Grilo, 2002; McGuire et al., 2001; Weller et al., 2008). Neuroimaging studies have investigated the neural foundations of decision-making and impulse control in eating-related tasks (Hare et al., 2009, 2011). They suggest that food decisions in self-reported dieters rely not only on value signals in ventromedial prefrontal cortex (VMPFC), but also on the degree to which control signals in dorsolateral prefrontal cortex (DLPFC) exert an influence over these value signals. Studies searching for neural correlates of longitudinal weight changes and impulse control exclusively investigated non-dieting subjects and either they failed to identify such signals (Batterink et al., 2010), or they were able to identify neural predictors of weight changes but were not able to link them to control behavior (Kishinevsky et al., 2012). Correspondingly, the complex relation

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between neurobehavioral parameters of impulse control and dietary success in obese subjects is still unclear.

Here, we investigated the link between behavioral impulsivity and their neural correlates *acquired before the onset* of a twelve-week low calorie diet in obese subjects and the corresponding weight loss obtained after the diet. We separately assessed the prognostic information contained in behavioral parameters of control, its neural correlates and the network connectivity of areas involved in decision-making. We found that a) higher impulse control is associated with better dietary success, b) future dietary success correlates with local brain activity in reward-related areas and areas involved in impulse control, and finally c) dietary success correlates with functional connectivity between reward- and control-related brain structures reflecting the degree of control applied to food-decisions.

Methods and materials

Participants

Participants were first invited via newspaper announcements and notifications in hospitals to participate in a larger dietary study. The inclusion criteria for this study were an age in the range of 18 to 70 years and a BMI of at least 30 when no cardiovascular risk factor such as arterial hypertension was present or a BMI of at least 27 when such a factor was present. Subjects with endocrine diseases, malabsorption, food allergies, hypertonia, recent changes in smoking behavior, and pharmacological treatments known to affect energy homeostasis, subjects participating in a diet in a two month interval preceding the study and subjects with weight changes of more than 5 kg in this period were excluded. Subjects included in the larger diet study were invited verbally to participate in the fMRI study. If they agreed, they were screened with a standardized clinical interview for mental disorders (Margraf et al., 2005) by a clinical psychologist (MW) in the second stage. If screening indicated an affective, anxiety, or delusional disorder, borderline personality disorder, or substance abuse, the subject was excluded. Furthermore, subjects were asked if they ever had a/whether they were ever diagnosed with Multiple Sclerosis, Parkinson's Disease, dementia, stroke, epilepsy, brain tumor, or whether they have ever had a brain surgery. When this screening indicated a positive result, subjects were excluded. 22 subjects that passed this screening procedure and did not have standard MRI contraindications performed a delayed gratification pilot run (see Delayed gratification task). Four of the 22 subjects did not show variations in decision behavior (e.g., always chose the delayed meal option) and were thus excluded. Finally, another two subjects were excluded that showed inconsistent decision behavior between the behavioral pilot and fMRI delayed gratification runs (cf., Kishinevsky et al., 2012). Thus, finally 16 (13 females) subjects were included in the fMRI study. Their mean age was M = 43.0 yrs (SD = 12.2 yrs; range: 23.5 yrs–66.5 yrs). Their mean pre-diet BMI was M = 34.5 (SD = 3.2; range: 29.8–41.5). On average, the dietary BMI-reduction was M = 4.3 (SD = 1.8; range: 0.7–7.7). The mean weight loss in kilograms was M = 12.7 kg (SD = 5.4 kg; range = 1.9 kg–20.5 kg). Finally, on average the subjects dropped to M = 87.4% (SD = 5.2%; range: 77.0%–98.0%) of their baseline weight in kilogram during the weight reduction program. Subjects obtained 10€ for participation in the screening session and 30€ for participation in the fMRI session. All participants provided written, informed consent. The study was approved by the ethics committee of the Charité — Universitätsmedizin Berlin.

Diet protocol

Weight loss was induced using a dietary protocol with a length of 12 weeks. The protocol consisted of three components: caloric restriction, nutritional counseling and physical exercises. Caloric restriction applied in the weight reduction program can be separated in two stages. In the first stage that lasted for 8 weeks, energy intake was restricted to 800 kcal per day by using a formula diet (Optifast 2®, Nestlé HealthCare Nutrition GmbH, Frankfurt am Main, Germany). During this period, subjects received 35 portions of the formula diet for a week (i.e. 5 per day) in weekly meetings with a nutritionist and were advised not to consume any additional food. In case that they were not able to follow this caloric restriction, they were instructed to document the amount of additional food consumed. The amount of consumed formula diet portions (and if applicable: additional food) was then documented in the meeting of the next week. In these meetings, also a medical monitoring was performed by a physician including patient interview, arterial blood pressure measurement, and blood test. Based on the blood sample, parameters for sodium, potassium, calcium, triglycerides and creatinine were determined in order to guarantee a compatible course of the weight reduction in terms of e.g. kidney and cardiac functioning. In the second stage of the weight reduction that lasted for 4 weeks, subjects were instructed to follow a calorie restricted standard diet composed in accordance with guidelines of the German Association of Nutrition (1500 kcal per day; 30% fat, 55% carbohydrates, 15% protein; cf. http://www.dge.de). Observance of the standard diet was supported by providing specific recipes, cooking advices, and instructions for behavior modifications (only 3 meals per day, at least 4 h break between the meals, reduced carbohydrate intake at dinner, support of increased physical activity independent of guided exercise training; see below). During that period, at least one body weight measurement per week was performed by a nutritionist at study site. During both stages of the program, i.e. the full 12-week period, weekly nutritional counseling group meetings (cooking courses) with a duration of 90 min were performed. In these group meetings subjects also performed guided physical exercise (aqua fitness or therapeutic exercise training) subsequent to the cooking courses for 30 min. On average, the dietary intervention program started M = 5.3 days (SD = 4.6 days; range: 0 days–14 days) after the fMRI session.

Stimuli and task

Delayed gratification task

This task was conducted twice during the study, i.e. once within a behavioral pilot on the day of recruitment in the hospital and once during fMRI scanning in four consecutive runs performed on a subsequent day. In both cases, the task was conducted between 8 and 11 a.m. to control for circadian oscillations of hormonal parameters. Subjects were asked to stop eating at 8 pm on the day before to guarantee that they were in a fasted state.

To tailor the paradigm to the individual subjects' food preferences, subjects had to state a preferred meal out of seven meals that varied in terms of calorie content on the day of recruitment in the hospital before the pilot. These meal options included typical breakfast and lunch meals. Specifically, subjects could chose among tomatoes with mozzarella, eggs and tomatoes, cereals with dried fruit, pasta salad, muffins, scallop, and pizza (Fig. 1). Subjects were told that they would not be gratified with a meal at the end of the task, but that decisions were made in an “as if” situation.

Each trial began with the presentation of a fixation screen, which was shown for two (behavioral pilot) or four to eight (fMRI scanning) seconds. In the following choice stage, a small portion of the favorite meal with the label ‘immediately’ appeared on one randomly selected side of the screen. On the other side, a larger portion of the meal was shown together with a label indicating a specific delay of gratification for the larger alternative. The subject was instructed to select their preferred choice with a button press. After the button press the arrow beneath the chosen meal changed its color from yellow to red to indicate successful selection in the feedback stage. The total duration of the choice and feedback stage was 6 s. After the feedback stage, the next trial started (see Fig. 1).