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ABSTRACT

In the current study we tried to elucidate the relationship between a personality trait, reward sensitivity, and an environmental variable; food variety. Based on scarce previous research we predicted that reward sensitivity would interact with variety in the food environment so that especially high reward sensitive individuals would be vulnerable to overeating in a varied food environment. It turned out that especially the high reward individuals did indeed overeat in a varied food environment. However, this was only the case for the highly reward sensitive individuals who experienced feelings of hunger. In other words, reward sensitivity does not affect food intake in varied food environments as long as feelings of hunger are not present. Future research should concentrate on identifying other factors that interact with the person and the environment to discourage reward-related overeating.

1. Introduction

In the battle against overweight and obesity finding out what drives people toward a positive energy balance is of paramount importance (Blundell & Finlayson, 2004). Investigating determinants of specific behaviors that lead to an unhealthy diet and a low level of physical activity is considered an important step toward successful health promotion (Kremers, 2010).

One of the determinants of energy balance-related behaviors such as frequent consumption of high-fat energy-dense foods is reward sensitivity (Davis et al., 2007). Reward sensitivity is a construct that stems from addiction research. It is seen as one of the traits that leads to impulsive behavior and can be measured both through self-report questionnaires and through behavioral paradigms (Guerrieri, Nederkoorn, & Jansen, 2008b). Individuals who are highly reward sensitive detect rewarding stimuli in their environment more easily and are more likely to approach these rewarding stimuli (Davis & Fox, 2008). Oftentimes this leads to the pursuit of immediate reward at the expense of long-term goals. For example, in a study measuring eye movements it was shown that food pictures grabbed the attention of overweight participants quicker compared to healthy weight participants. Moreover, this increased attention-grabbing of food stimuli was linked to increased craving and food consumption (Werthmann et al., 2011). Other previous research has linked higher reward sensitivity to obesity in children (Nederkoorn, Braet, Van Eijs, Tanghe, & Jansen, 2006) and adults (Davis, Levitan, Muglia, Bewell, & Kennedy, 2004) and to overeating in healthy children (Guerrieri, Nederkoorn, & Jansen, 2008a).

Not only factors to do with the individual such as reward sensitivity, but also characteristics of the food environment that one is exposed to can trigger overeating. It is quite commonly accepted that our food environment has become “toxic” or “obesogenic” (Hill & Peters, 1998). In other words, sweet and fatty foods are highly varied, cheap, easily available and offered in increasingly large portion sizes (Drewnowski, 2004; McCrory et al., 1999; Nielsen & Popkin, 2003; Nielsen, Siega-Riz, & Popkin, 2002). Research has indicated that these sorts of environmental variables have a more powerful influence on eating behavior than the biological processes that regulate food intake according to the homeostatic model (Levitsky, 2005). In sum, there is reason to believe that both personality factors such as reward sensitivity and environmental factors such as food variety have a considerable influence on food intake in humans.

A hypothesis that has been theoretically suggested multiple times (Blundell et al., 2005; Kremers, 2010), but that has been largely overlooked in research is the interaction hypothesis. It is feasible that personality factors interact with environmental factors in the sense that a personality characteristic can work protectively against or, alternatively, might enhance the environmental factor's effect on eating behavior. For example, it has been suggested that reward sensitive individuals are particularly vulnerable to temptations in the obesogenic environment and are thus in particular danger of constant overeating (Blundell et al., 2005). To the authors' knowledge this hypothesis has been tested twice. Guerrieri et al. (2008a) found that children who scored high on

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a behavioral task measuring reward sensitivity only overate when they were placed in a varied food environment, whereas they did not differ from low reward-sensitive children when placed in a monotonous food environment. Paquet et al. (2010) found that fast-food restaurant exposure within 500 m of participants' residence would only predict increased fast-food consumption for the high reward-sensitive participants. It should be noted that reward-sensitivity was measured using self-report as opposed to the behavioral paradigm that was used in the current study.

Another factor that might affect whether reward sensitive individuals will more easily overeat in a toxic environment is state hunger, both in its homeostatic and hedonic nature (Blundell & Finlayson, 2004). A recent fMRI study confirmed that an 18-hour food deprivation boosts activity in the brain's reward centers (Siep et al., 2009). It is thus feasible that especially high reward sensitive individuals who are hungry overeat in a varied food environment, much like the effect of insufficient response inhibition on overeating turned out to be moderated by hunger in a study by Nederkoorn, Guerrieri, Havermans, Roefs, and Jansen (2009).

In sum, the current study has two aims. First, given the scarcity of this kind of research, a first aim of this paper is to replicate the findings of Paquet et al. (2010) and Guerrieri et al. (2008b) using behavioral paradigms of reward sensitivity and measuring food intake of monotonous versus varied food. It is expected that especially highly reward sensitive individuals will overeat in a varied food environment. Second, we predict that hunger will trigger or enhance the effect of reward sensitivity on food intake in a varied food environment. In other words, in particular the high reward sensitive individuals who are hungry are expected to overeat in a varied food environment.

2. Method

2.1. Participants

Eighty female undergraduate students, all of Western European origin (Dutch, Belgian, or German; mean BMI: 22.81 ± 3.39; BMI range: 17.64–33.61) were recruited to participate in a study on "cognitive and sensory abilities." All participants were randomly assigned to the monotony or variety condition and they were tested individually. Three participants failed to indicate hunger levels and were thus not included in the statistical analyses. All the remaining participants' data were used since they all adhered to the instructions and had no suspicions concerning the true hypotheses of this study. Participants received course credit or a monetary reward of €10 for their participation. The procedure of the study was approved by the university's ethical committee.

2.2. Materials

Hunger was measured by posing the question "How hungry are you at this moment?" using a 100-mm Visual Analogue Scale (VAS), ranging from 0 (not at all hungry) to 100 (very hungry).

The *Iowa Gambling Task* (IGT) was originally developed to capture the impaired decision-making in the form of insensitivity to future consequences that results from ventromedial prefrontal cortex damage (Bechara, Damasio, Damasio, & Anderson, 1994). Later on, it was used to show that a large subgroup of substance dependent individuals favored choices that yielded high immediate gains in spite of even higher future losses i.e. were more sensitive to reward (Bechara, Dolan, & Hindes, 2002). The IGT has been validated for use with several clinical groups (Buelow & Suhr, 2009) and it has also been linked to overeating in the sense that people with poor decision making abilities as measured by the IGT tended to have a higher BMI compared to those who were able to make good decisions (Davis et al., 2004). The IGT is a card selection task in which participants can earn and lose money with each card they select. Some decks, A and B, are disadvantageous since high yields are counteracted with even higher losses. Other decks, C and D, are advantageous since the small yields, combined with small losses lead to a net gain in the long run. Participants do not get this information, but healthy controls do figure out what the nature of the stacks is after a number of exploratory trials and will stick to the advantageous stacks (Bechara et al., 1994). The larger the proportion of cards chosen from disadvantageous decks, the more reward-sensitive an individual is believed to be. In this study participants received a computerized version of the IGT consisting of fifty trials.

A *Bogus Taste Test* was used in order to measure food intake of the participants in an unobtrusive way. Participants were left alone for 15 min to taste and rate bite-size cookies that were placed in front of them in a large bowl. In the monotony condition participants received a bowl filled with chocolate-chip cookies (± 400 g), whereas participants in the variety condition received a bowl filled with four sorts of cookies (± 100 g of each sort): the chocolate chip cookies (510 kcal/100 g), coconut macaroons (475 kcal/100 g), sponge-like biscuits filled with orange jam and covered in bitter chocolate (395 kcal/100 g), and milk chocolate-covered cookies filled with vanilla cream (490 kcal/100 g). Participants had to rate odor, general appeal, palatability, sweetness, crunchiness and creaminess. However, the primary interest of the authors was not how participants rated the taste of the cookies, but how much they consumed during the taste test. Without the participants' knowledge the bowl of cookies was weighed before and after the taste test in order to establish food intake. In the variety condition the four sorts of cookies were weighed in separate bowls before and after the taste test, but they were presented to the participants in one bowl. The amount of grams eaten of each cookie was converted into calories. The sum of these calories was the dependent variable: total caloric intake.

2.3. Procedure

At recruitment all participants were asked to eat something small like a cheese sandwich 3 h before they were to come to the lab and to otherwise refrain from eating and drinking (except water) until the time of testing. Participants received a reminder by e-mail the day before the experimental session and at the end of the session we checked whether they had adhered to the instructions. At the lab, we obtained informed consent and general information (study year, age, etc.) and measured hunger before participants performed the Iowa Gambling Task (IGT). This took about 10 min. Next the taste test was performed, followed by the filling out of questionnaires (adherence to instructions, and suspiciousness of hypotheses). After the participants' length and weight (in light clothing and in stocking feet) had been measured, they received their course credit or monetary reward and were thanked and dismissed.

2.4. Analyses

A linear regression model was used to predict caloric intake. The predictors that were entered were condition (dummy-coded), reward sensitivity (number of disadvantageous cards in IGT) and hunger (score on VAS scale). All of these variables' two-way interactions and the three-way interaction were also entered. All variables were centered before they were entered into the linear regression model.

3. Results

The linear regression model is presented in Table 1. The overall model significantly predicted caloric intake, $r^2 = 0.24$, $F(7, 69) = 4.43$, $p = 0.00$. Condition (monotony versus variety) proved to be a significant predictor of caloric intake and hunger was a marginally significant predictor of food intake. Hunger interacted with reward to predict food intake. However, this effect was moderated by condition, leading to a significant three-way interaction (see Fig. 1a and b

Table 1
Summary of linear regression analysis for variables predicting caloric intake (n = 77).

Variable	B	*SE* B	Beta	*p*
Condition (variety vs. monotony)	132.47	30.85	0.46	0.000
Reward	−0.01	3.04	0.00	0.997
Hunger	0.16	0.09	0.31	0.065
Reward × condition	0.76	3.73	0.05	0.839
Hunger × condition	−0.12	0.11	−0.17	0.292
Hunger × reward	0.04	0.02	0.72	0.020
Hunger × reward × condition	−0.03	0.02	−0.62	0.046

for plots). In other words, especially high reward sensitive participants overeat when hungry, but only when they are placed in a varied food environment. See Table 2 for overall descriptives of the main variables.

4. Discussion

In the current study we tried to elucidate the relationship between the individual factor reward sensitivity, the environmental variable food variety and the state variable feelings of hunger. Based on scarce previous research we predicted that reward sensitivity would interact with variety in the food environment so that especially reward sensitive individuals would be vulnerable to overeating in a varied food environment. Moreover, we predicted that feelings of hunger would moderate this effect.

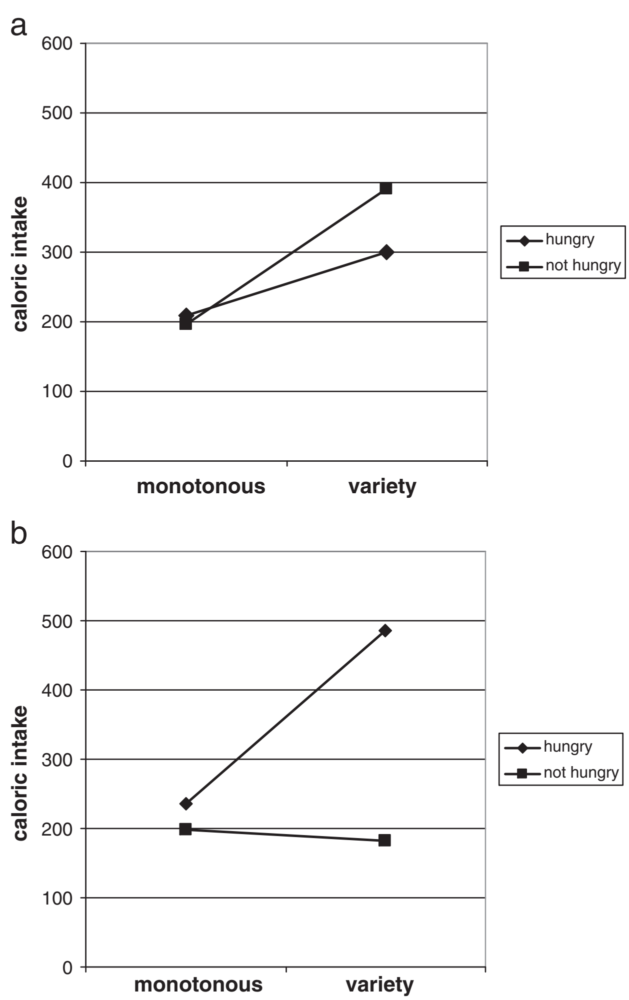

Fig. 1. a. Caloric intake for low reward sensitive participants as a function of feelings of hunger (1 SD below and 1 SD above the mean hunger rating) and condition (monotonous versus varied food). b. Caloric intake for high reward sensitive participants as a function of feelings of hunger (1 SD below and 1 SD above the mean hunger rating) and condition (monotonous versus varied food).

Table 2
Overall descriptives of main variables (n = 77).

	Mean	SD
IGT score (0–50)	28.91	10.28
Hunger score (0–100)	48.52	27.15
Caloric intake	275.10	145.95

It indeed turned out that especially the high reward sensitive individuals did overeat in a varied food environment. Interestingly, this was only the case for the individuals who experienced feelings of hunger. In other words, caloric intake was determined by an interaction of reward sensitivity, food environment and feelings of hunger. The high reward sensitive individuals who experienced feelings of hunger in a varied food environment had the highest caloric intake of all groups.

A surprising result was that the high reward sensitive participants who did not feel hungry were the only group that did not overeat in the varied food environment compared to their counterparts in the monotonous environment (198 versus 183 kcal). This could mean that being reward sensitive does not lead to overeating in a varied environment per se. It seems that high reward sensitive individuals are especially vulnerable when they feel hungry. However, when they do not feel hungry, high reward sensitive individuals seem to be rather immune to the effects of a varied food environment, whereas the low reward sensitive individuals overeat regardless of hunger. An explanation for this result could be that reward sensitive individuals are only sensitive to a certain reward when it is relevant to them: specific reward sensitivity might be state-dependent, e.g., food reward sensitivity only leads to increased intake of high caloric foods when one is hungry. Previous research has shown that high caloric foods elicit strong activity in reward related brain areas, and is thus an especially relevant reward, only when one is feeling hungry (Siep et al., 2009).

However, this observation also makes us wonder whether high reward sensitive individuals are more self-focused than low reward individuals, and thus more aware of their feelings of hunger, and act accordingly. This could explain why the high reward sensitive individuals in this sample are extremely vulnerable to changes in their food surroundings when they are hungry, whereas they are not affected by these changes when they are not hungry.

Reward sensitivity is not the only aspect of impulsive behavior that turns out to be moderated by hunger. Nederkoorn et al. (2009) demonstrated the same effect for another aspect of impulsivity: insufficient prepotent response inhibition. Participants that scored lower on a general behavioral test of response inhibition ingested more calories during a taste test and bought more calories when shopping in a virtual supermarket, but only when they were feeling hungry. It appears therefore that the broader concept of impulsivity interacts with hunger on its effect of eating.

It seems that the effect of impulsive traits on eating behavior is not simple, but moderated by third factors. Hunger seems to be one factor, and preferences for snack food might be another factor (Nederkoorn, Houben, Hofmann, Roefs, & Jansen, 2010). Age might also be an important factor, since a two-way interaction emerged in a previous study with 8- to 10-year-old children (Guerrieri et al., 2008a), showing an effect of reward sensitivity on overeating in a varied environment irrespective of feelings of hunger. Future research should concentrate on looking into these moderating factors. It is clear that impulsive traits encourage overeating, but it is unclear under which circumstances this effect is triggered.

Although this study used a sample normal-weight healthy participants, its outcomes can be linked to overeating problems of clinical proportions as seen in Binge Eating Disorder (BED) and obesity. It has been shown that both BED patients (Manwaring, Green, Myerson, Strube, & Wilfley, 2011; Schienle, Schäfer, Hermann, & Vaitl, 2009) and obese patients (Davis et al., 2004; Nederkoorn et al., 2006) are significantly more reward sensitive, compared to normal-weight participants. Moreover, binge eating has been linked to increased feelings of hunger (Haedt-Matt & Keel, 2011) and hunger has been identified as an obstacle in the treatment of BED; patients who abstained from bingeing after treatment were significantly less hungry – as measured by the Eating Inventory – compared to patients who did not manage to abstain (Downe, Goldfein, & Devlin, 2009). In obesity following a regular meal pattern in order to avoid hunger feelings avoiding hunger feelings is linked to weight loss maintenance and more hunger is associated with weight regain.

The concept of hunger is incorporated in Cognitive Behavioral Therapy (CBT) for BED (Waller et al., 2010) and obesity (Sibilia, 2010). The thought that binges and other forms of overeating are uncontrollable or unpredictable is challenged. They occur after certain physical (e.g. hunger) or psychological events (e.g. negative emotions). In order to make sure that hunger cannot lead to bingeing or overeating, patients are recommended not to leave more than 3–4 h between planned eating episodes (Waller et al., 2010).

The outcomes of the current study confirm that it is especially difficult to resist palatable food when one is reward sensitive and hungry. It thus supports the importance of dealing with hunger in the treatment of BED and obesity. However, this support is quite indirect. It is a considerable limitation of this study that the sample consisted of normal-weight, healthy female university students who are probably quite low in reward sensitivity. It would be informative to replicate this study with a sample of highly reward sensitive healthy participants, and with a sample of clinically obese (BED) patients. If this effect were to be confirmed within a clinical group, then this would certainly warrant further attention to hunger feelings in the treatment of BED and obesity. If highly reward sensitive but healthy participants also exhibit this effect, this would support the hypothesis that increased feelings of hunger are possibly a causal factor in the etiology of obesity and BED. There is evidence that eating in the *absence* of hunger is a behavior that marks a predisposition toward obesity (Faith et al., 2006; Fischer & Birch, 2002). It would be interesting to test these two view points by having three conditions. First, a hunger condition in which participants are food deprived for a considerable amount of time. Second, a control condition in which participants are deprived of food for a couple of hours so that they are not particularly hungry or full. Third, a full condition in which participants are allowed to eat until satiated just before the experiment.

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Contributors

R. Guerrieri designed the study, wrote the protocol, conducted statistical analyses, and wrote the first draft and final version of the manuscript.

N. Stanczyk designed the study, wrote the protocol, tested participants, and conducted statistical analyses.

C. Nederkoorn designed the study and contributed to the final version of the manuscript.

A. Jansen designed the study and contributed to the final version of the manuscript.

All authors have approved the final manuscript.

Conflict of interest

All authors declare that they have no conflicts of interest.

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