Eating behavior style predicts craving and anxiety experienced in food-related virtual environments by patients with eating disorders and healthy controls

Marta Ferrer-García[1], Joana Pla-Sanjuanelo[1], Antonios Dakanalis[2], Ferran Vilalta-Abella[1], Giuseppe Riva[3], Fernando Fernandez-Aranda[4], Isabel Sánchez[4], Joan Ribas-Sabaté[5], Alexis Andreu-Gracia[5], Neli Escandón-Nagel[6], Osane Gomez-Tricio[7], Virginia Tena[8], José Gutierrez-Maldonado[1]

[1]Department of Clinical Psychology and Psychobiology, University of Barcelona, Barcelona, Spain

[2] Department of Medicine and Surgery, University of Milano Bicocca, Milan, Italy

[3]Applied Technology for Neuro-Psychology Lab. Istituto Auxologico Italiano, Milan, Italy

[4] Department of Psychiatry, University Hospital of Bellvitge-IDIBELL, Barcelona, Spain

[5]Department of Psychiatry and Mental Health, Igualada General Hospital, Barcelona, Spain

[6] Catholic University of Temuco, Chile

[7]Department of Psychiatry, University Hospital Joan XXIII, Spain

[8]Centro ABB Tarragona, Spain

Abstract

Eating behavior style (emotional, restrictive, or external) has been proposed as an explanation for the differences in response to food-related cues between people who overeat and those who do not, and has been also considered a target for the treatment of eating disorders (EDs) characterized by lack of control over eating and weight-related (overweight/obesity) conditions. The aim of this study was to analyze the relationship between eating behavior style and psychophysiological responses (self-reported food craving and anxiety) to food-related

Correspondence to:

Marta Ferrer-Garcia
Department of Clinical Psychology and Psychobiology
University of Barcelona
Paseo Valle de Hebrón, 171
08035, Barcelona, Spain
Phone: 0034933125114
Fax: 0034934021362
E-mail: martaferrerg@ub.edu

virtual reality (VR) environments in outpatients with bulimia nervosa (BN) and binge eating disorder (BED) and to compare them with healthy participants. Fifty-eight outpatients and 135 healthy participants were exposed to palatable foods in four experimental everyday real-life VR environments (kitchen, dining room, bedroom and café). During exposure, cue-elicited food craving and anxiety were assessed. Participants also completed standardized instruments for the study purposes. ED patients reported significantly higher levels of craving and anxiety when exposed to the virtual food than healthy controls. Eating behavior styles showed strong associations with cue-elicited food craving and anxiety. In the healthy group, external eating was the only predictor of cue-elicited craving and anxiety. In participants with BN and BED, external and emotional eating were the best predictors of cue-elicited craving and anxiety, respectively.

KEYWORDS: Food craving, anxiety, external eating, emotional eating, restraint eating, virtual reality, cue-exposure therapy, bulimia nervosa, binge eating disorder

INTRODUCTION

Overweight (Body mass index, BMI ≥ 25 kg/m2) and obesity (BMI ≥ 30 kg/m2) have grown alarmingly during last years in most world's countries. According to the World Health Organization (WHO), in 2014, 39% of adults aged 18 years and over (38% of men and 40% of women) were overweight and 13% (11% of men and 15% of women) were obese (WHO, 2015). This is more than half of the world's adult population and data are not more encouraging when analyzing pediatric samples. Beyond body image dissatisfaction and self-esteem concerns, these conditions are associated with chronic adverse health effects, disability, social stigmatization and a reduction in the overall quality of life and life expectancy (Calle, Teras, & Thun, 2005; Capodaglio, Faintuch, & Liuzzi, 2013; Malnick & Knobler, 2006; Riva, Gaggioli, & Dakanalis, 2013). Importantly, binge eating (wherein one consumes a large amount of food whilst experiencing a sense of loss of control over eating) required for diagnoses of bulimia nervosa (BN) and binge eating disorder (BED) (American Psychiatric Association [APA], 2013), is a consistent predictor of overweight status and strongly associated with greater obesity severity, and increased risk for obesity-related chronic illnesses (Sonneville et al., 2013; Tanofsky-Kraff et al., 2009).

Relevant explanations of human overweight and obesity include the growth of modern lifestyles with the availability of energy-dense food and the rise of sedentariness (Capodaglio et al., 2013; Maffeis, 2000). Despite the potency of this obesogenic environment, however, not all people become overweight (van Strien, Herman, & Verheijden, 2009). Indeed, there are individual differences that may moderate and/or mediate responses to continuous exposure to high palatable food-related stimuli (Blundell et al., 2005). Eating styles (i.e., specific patterns of eating) have been proposed to explain response differences to obesogenic environments (Burton, Smit, & Lightowler, 2007; van Strien, Herman, & Verheijden, 2012). Three main eating styles, having their own aetiology (see below), are thought to be closely associated to overeating and weight gain –emotional, restrictive and external eating (Braet & van Strien, 1997; Dakanalis et al., 2013, 2014; Van Strien, Herman, & Verheijden, 2012).

Emotional eating or eating in response to internal emotional factors (i.e., fear, anxiety) is recognized as a risk factor for developing overweight (Van Strien, Herman, & Verheijden, 2012) and has been extensively addressed by the psychosomatic theory (Bruch, 1964). According to this theory and related longitudinal research (Dakanalis et al., 2014) increased food intake in response to emotional distress may occur in some individuals who, as a result of learning experiences early in life where food was used as a way of coping with psychological

distress, confuse internal emotional factors with hunger, due to poor interoceptive awareness. Likewise, individuals may paradoxically develop an overweight physique by consciously restricting food intake to lose or maintain a particular body weight (i.e., restrained eating) irrespective of whether they are emotional or external eaters (Van Strien, Frijters, Bergers, & Defares, 1986). This eating pattern was addressed by Herman and Polivy's (1980) theory of restrained eating and based on their laboratory work, in which individuals who restrained their food intake overate when their self-control was deliberately undermined. Eating in response to external stimuli (i.e., external eating), involving a decreased sensitivity to internal signals of hunger and satiety, has been addressed by externality theory (Schachter, 1971), according to which overweight/obese people are externally controlled or stimulus-bound, i.e., more reactive to food-related external cues and less sensitive to internal hunger and satiety signals than normal-weight people. While both the psychosomatic and externality theories start from the premise that people with overeating behavior have a lower awareness of internal signals of hunger and satiety, the externality theory goes further by highlighting that overeaters have also a heightened responsiveness to external cues of food, such as the smell, sight, and taste of food. Consequently, intake in overweight people would be externally guided, which represents a major problem if we take into account the huge number of food-related stimuli that continually bombard us in the modern world. By reviewing the history of and research on "external cues" as an important factor in the control of human food intake, Herman and Polivy (2008) introduced a distinction between normative and sensory external cues. According these authors, normative cues (e.g., portion size) refer to indicators of appropriate intake and affect all eaters indiscriminately, whereas sensory cues that refer to the properties of the food that make it more or less appetizing (e.g., high palatability) have a more powerful effect on certain people (obese, dieting, or hungry individuals); for further details, including evidence that the sensory effect is grounded in physiology, see, Herman and Polivy (2008).

A heightened reactivity to environmental food-related cues such as the sight and smell of food has been proposed to increase food craving, i.e. an appetitive motivational state that promotes the ingestion of desired foods (Brockmeyer et al. 2015) even in a state of satiety, and consequently, food intake (Burton et al., 2007; Ferriday & Brunstrom, 2011; Nederkoorn & Jansen, 2002; Nederkoorn, Smulders, & Jansen, 2000; van Strien et al., 2012). However, research reveals that not only the external eating style (Nederkoorn, Smulders, Havermans, & Jansen, 2004; Nederkoon, Smulders, & Jansen, 2000; van Strien & Ouwens, 2003) but also the restraint (Cepeda-Benito, Fernandez, & Moreno, 2003; Dakanalis et al., 2015; Hill, Weaver, &

Blundell, 1991; Nammi, Saisudha, Chinnala, & Boini, 2004) and emotional eating (Dakanalis et al., 2014; Davis, Levitan, Smith, Tweed, & Curtis, 2006; Deaver, Miltenberger, Smyth, Meidinger, & Crosby, 2003; van Strien et al., 2009; Wardle et al., 1992) styles are related to higher levels of food craving and binge eating. Given also the positive associations between food cravings and excessive overeating (Brockmeyer et al., 2015; Hetherington & Mcdiarmid, 1995), BMI (Burton et al., 2007) binge eating, BED and BN (Chao, Grilo, & Sinha, 2016; Greeno, Wing, & Schiffman, 2000; Joyner, Gearhardt, & White, 2015; Waters, Hill, & Waller, 2001), an increasing body of studies have focused on the relation between eating styles, food craving (a frequently cited antecedent of binge eating; Chao, et al., 2016; Schulte, Grilo & Gearhardt, 2016), and lack of control over eating. The results of these studies have been inconsistent to date, emphasizing the complexity of these relations. In their research, Burton and colleagues (2007) found external eating to be the principal predictor of food craving in both males and females; however, restrained eating was negatively associated with craving in females, while emotional eating was not significantly associated with food craving. In other research, a positive and significant correlation between binge behavior and both external eating and emotional eating has been found (Mason & Lewis, 2014). Such responsiveness to food cues is not specific to overweight people according to van Strien and colleagues (2009), but is a general characteristic of humans. Indeed, according to Rodin (1981), external eating may be an evolutionary adaptive response that is related to the concept of a thrifty genotype (Neel, 1962).

Heightened reactivity to food-related cues has also been proposed to elicit anxiety in individuals with binge behaviors. Martínez-Mallén et al. (2007) stated that exposure to food-related cues elicits not only food craving but also anticipatory anxiety, and that it is this anxiety that leads to binge behaviors. On the bases of this model, the association between food-related cues and anxiety is established during the initial stages of the bulimic condition. After binges, individuals experience negative emotions, such as shame, guilty, and discomfort. With time, people who binge associate those foods usually eaten during binges, as well as other specific and contextual cues (environmental and temporal), with high levels of anticipatory anxiety. This anxiety can lead to what the authors name “bulimic hunger” (Martínez-Mallén et al.,2007). Despite the fact that this model has not been studied enough, data suggest that anxiety elicited by food exposure better discriminates between clinical and non-clinical samples than craving (Pla-Sanjuanelo et al., submitted). Whereas a certain level of craving is expected to be found in non-clinical samples when they are exposed to palatable food (Ferrer-Garcia,

Gutiérrez-Maldonado, Treasure, & Vilalta-Abella, 2015; Nederkoorn, Smulders, Havermans, Jansen, 2004), anxiety levels are expected to be low in these samples, given that food is not a stressful stimulus for healthy people.

Taking into account these studies, it may be worth considering patients' eating styles in the treatment of eating disorders (EDs) characterized by binge eating (i.e., BN and BED) and weight-related (overweight/obesity) conditions. Indeed, theoretical models based on the study of external food-cue reactivity (Schachter, 1971) provide a rationale for exposure with response prevention of bingeing, also known as cue-exposure therapy (CET) (Gutiérrez-Maldonado, Ferrer-Garcia, & Riva, 2013; Koskina, Campbell, & Schmidt, 2013). According to the conditioning model of binge eating (Jansen, 1998) highlighting the learning processes that underlie physiological and craving responses to food cues, repeated exposure to specific stimuli (food-related cues that are systematically associated with binge eating, such as the presence of high caloric food) provokes a psychophysiological response that is subjectively experienced as food craving, and triggers binge eating. When binging occurs, its association with food cues is reinforced, thereby increasing the probability of further binge episodes. CET aims to extinguish the craving response by breaking the link between the conditioned and the unconditioned stimuli through the repeated exposure to food-related cues (conditioned stimuli) while binging (unconditioned stimulus) is prevented (Koskina et al. 2013). As abovementioned, Martínez-Mallén et al. (2007) proposed a variation of this model and stated that exposure to food-related cues also elicits anticipatory anxiety, being this anxiety which triggers binge behavior. Linked with the specification of Herman and Polivy (2008), the conditioned stimuli would include both normative and sensory food cues, with the latter particularly affecting patients with binge eating behavior.

Although several studies, reviewed elsewhere (Gutiérrez-Maldonado et al., 2013; Koskina et al., 2013) have provided evidence of the efficacy of CET for the treatment of EDs characterized by binge-eating, the use of CET has not become widespread, probably because CET did not add significant benefits to cognitive behavioral therapy (Bulik, Sullivan, Carter, McIntosh, & Joyce, 1998) (CBT), mainly due its logistic complexity (Bulik et al., 1998; Martínez-Mallén et al., 2007). As an alternative to in vivo therapy, virtual reality (VR) technology has been proposed as a means of administering CET (Gutiérrez-Maldonado, Wiederhold, & Riva, 2016). VR, which has demonstrated its efficacy as a tool for assessing and treating EDs (Ferrer-Garcia, Gutiérrez-Maldonado, & Riva, 2013), overcomes the characteristic logistical drawbacks of in vivo exposure, and the process allows therapists to

maintain high levels of control over the exposure situation, as well as the ability to expose patients to contextual and specific cues.

Previous research provides evidence of the ability of VR environments to generate emotional and behavioral responses in ED patients similar to those expected in real-life situations (Aimé, Cotton, & Bouchard, 2009; Ferrer-Garcia, Gutiérrez-Maldonado, Caqueo-Urízar, & Moreno, 2009; Gorini, Griez, Petrova, & Riva, 2010; Gutiérrez-Maldonado, Ferrer-García, Caqueo-Urízar, & Moreno, 2010). There is even evidence that VR-based food-cue exposure can induce craving responses in both healthy and clinical (i.e., ED patients) groups (Agliaro-López, Ferrer-García, Pla-Sanjuanelo, & Gutiérrez-Maldonado, 2014; Ferrer-Garcia, Gutiérrez-Maldonado, & Pla, 2013; Ferrer-Garcia, Gutiérrez-Maldonado, Treasure, & Vilalta-Abella, 2015), though the results have not always been consistent (Ledoux, Nguyen, Bakos-Block, & Bordnick, 2013). Studies have shown that healthy participants reported higher levels of craving when exposed to high-calorie foods than when exposed to low-calorie foods (Ferrer-Garcia, Gutiérrez-Maldonado, Treasure et al.,2015) and that food craving experienced in VR environments was associated with trait and state food craving assessed outside VR environments (Agliaro-López et al., 2014; Ferrer-Garcia et al., 2013). More interestingly, reported food craving in these studies was similar to that found in studies conducted with real food (Tetley, Bunstrom, & Griffiths, 2009). However, not all food cues produced the same levels of craving. Consistent with Herman and Polivy's (2008) distinction between normative and sensory external cues, higher levels of craving were associated with exposure to highly palatable food in the aforementioned studies. Likewise, previous studies found that ED patients and individuals concerned with their weight and shape reported higher levels of anxiety when exposed to high-calorie foods than when exposed to low-calorie foods in VR environments (Aimé et al, 2009; Ferrer-Garcia et al., 2009; Ferrer-Garcia et al., 2015). Now, it is necessary to go a step further and deeper into the relationship between the reactivity to virtual food in VR environments and the eating behavior style reported by healthy controls and patients characterized by binge eating (i.e., with BN, BED).

The main objectives of this study are to: (a) analyze the relationship between eating style and psychophysiological responses to food-related VR environments (specifically, food craving and anxiety), and (b) evaluate whether this relationship was different in patients with ED (BN and BED) to that in healthy participants. A previous preliminary study by our group showed that an external eating style was the best predictor of food craving experienced in VR environments, after controlling for the percentage of variance explained by the presence of an

ED diagnosis (variable entered in the first step of a hierarchical multiple regression analyses) (Ferrer-Garcia, Gutiérrez-Maldonado, Pla-Sanjuanelo et al., 2015). In the present study, this research was replicated enlarging the sample and assessing participants with and without EDs separately in order to explore differences between the clinical and healthy/control groups. We also considered anxiety as a dependent variable because, along with food craving, it is known to be related to binge eating (Leehr, Krohmer, Schag, Dresler, Zipfel, & Giel, 2015; Satta et al., 2016). In accordance with abovementioned studies, a positive relationship was expected between the eating style and food craving experienced in VR environments. Given that individuals with an external eating style show a heightened responsiveness to external food-cues (Schachter, 1971), it was expected that the association between external eating style and food craving would be stronger than the association with emotional and restraint eating styles (H1). The relationship between eating style and food craving was expected to be stronger in patients with BN and BED than in healthy participants (H2). Likewise, it was expected that eating styles, especially external eating, would be good predictors of food craving experienced in the VR environments in both groups (H3). The association between eating behavior style and the presence of cue-elicited anxiety in the VR environments was also explored. Despite a lack of previous research addressing this issue, the already mentioned model proposed by Martínez-Mallén et al. (2007) was adopted, indicating that anxiety elicited by food cues leads to binge eating behavior in ED patients. Given that, a positive relationship was expected between the eating style, especially the external eating, and the anxiety experienced in the VR environments (H4). Again, this association was expected to be stronger in patients with BN and BED than in healthy participants (H5). It was also expected that the eating styles, especially the external eating, would be good predictors of anxiety experienced in the VR environments in both groups (H6).

METHODS

Participants

The clinical (ED) group included 58 outpatients (13 men and 45 women), of whom 33 met DSM-5 (APA, 2013) criteria for BN and 25 criteria for BED. Mean age was 33.94 years (SD = 10.84, range 18 to 63). Mean (measured) body mass index (BMI) was 27.26 (SD = 5.60, range from 17.95 to 40.61). All participants were recruited from collaborating hospitals and health centers including the Hospital de Bellvitge (Barcelona, Spain), Adult Mental Health

Center of the Consorcio Sanitario de la Anoia (Igualada, Spain), Hospital Universitari Joan XXIII (Tarragona, Spain), and the Instituto Auxologico Italiano (Milan, Italy). Inclusion criteria were a diagnosis of BN or BED according to DSM-5, and age over 18. Diagnostic interviews were conducted in each one of the participating hospitals. Patients with suicidal ideation or any comorbid psychiatric disorder were excluded from the study.

The control group consisted of 135 healthy participants (13 men and 122 women) recruited from among college students from the faculty of psychology at the University of Barcelona. Mean age was 23.39 years (SD = 4.35, range 19 to 56) and mean (measured) BMI 21.71 (SD = 3.01, range 16.58 to 34.77). Participants with (past or current) diagnosis of any ED or psychiatric disorder were excluded.

All participants gave their written informed consent prior to entry in the study. The protocol was approved by the research ethics committees of the collaborating institutions.

Instruments

Food CET software and hardware

VR-based software for CET in binge eating behaviors was recently developed and validated by our research group (Pla-Sanjuanelo et al., submitted). It includes a library of 30 virtual sweet and savory foods, frequently consumed by patients with ED during binge eating episodes (e.g. cake, pizza, chips, hot dog, cookies, ice-cream, chocolates, rolls/buns, donuts, brownies), as well as 4 everyday real-life VR environments where they usually binge (kitchen, dining room, bedroom, and cafeteria) (Pla-Sanjuanelo et al., 2015). Non-immersive virtual environments were displayed on a 15.6-inch stereoscopic monitor (Pla-Sanjuanelo et al., submitted). Earphones and polarized glasses were also used.

Measures

The *eating behavior style* was assessed using the Spanish (Cebolla, Barrada, van Strien, Oliver, & Baños, 2014) and Italian (Dakanalis et al., 2013) versions of the Dutch Eating Behavior Questionnaire (DEBQ; Van Strien, Frijter, Bergers, & Defares, 1986). This questionnaire contains 33 items grouped in three subscales: emotional eating (13 items), external eating (10 items), and restraint eating (10 items). All items are rated on 5-point scales with response categories ranging from 1 (never) to 5 (very often). The references provided contain information regarding the psychometric properties of the original Spanish and Italian

versions of the instrument. In the current study, the alpha coefficients were .93, .85 and .93 for emotional eating, external eating, and restraint eating respectively.

In line with previous research (Pla-Sanjuanelo et al., 2015) revealing a significant association between food craving and the *frequency/severity of binge eating behavior* assessed through the Bulimia subscale of the EDI-3 (EDI-B), this subscale was also administrated. The Spanish (Elosua, López-Jáuregui, & Sánchez-Sánchez, 2010; Elosua & López-Jáuregui, 2012) and Italian (Garner, 2008) adaptations of the EDI-3 (Garner, 2004) were used in the current study. The EDI-B measures the individual's tendency to engage in episodes of uncontrollable overeating (*binge eating*) (Garner, 2004, 2008; Dakanalis et al., 2014) on a 5-point scale from 0 (never) to 4 (always). The subscale, which has demonstrated good psychometric properties (Elosua et al. 2010; Elosua & López-Jáuregui, 2012; Garner, 2004, 2008), showed good reliability ($\alpha = .96$) in this study.

Food craving and anxiety experienced in the VR environments were measured using a 100 mm visual analog scale (VAS) (Parker et al., 2004), anchored with the statements "Set on the bar, from 0 (not at all) to 100 (extremely), the level of food craving you experience at this time" and "Set on the bar, from 0 (not at all) to 100 (extremely), the level of anxiety you experience at this time". The VAS appeared on a computer screen, and participants were asked to click a point on the bar that best represented their level of craving or anxiety at that moment. Food craving and anxiety experienced in VR environments was associated with trait and state food craving and anxiety assessed outside VR environments (Pla-Sanjuanelo et al., submitted).

Design and procedure

This study followed a cross-sectional design in a single session, where the eating behavior style of the participants (assessed with the DEBQ) was considered the independent variable (predictor), whereas reported food craving and anxiety (assessed with VASs) during exposure to the virtual environments were considered dependent variables. Participants were informed of the nature of the study by the experimenter responsible for its administration. During the session, an experienced clinician accompanied the participant to offer help if needed.

After completing the DEBQ and EDI-B and reporting information regarding the length of time since the last meal (in minutes), study participants were exposed to the VR-based software developed for CET in binge eating (Pla-Sanjuanelo et al., submitted). First, they were exposed to a list of 30 bi-dimensional (2D) images of different virtual foods and asked to

indicate the level of craving elicited by each food on a VAS ranged from 0 (not at all) to 100 (extreme), placed under each image. After this, they were exposed to a list of four 2D images of everyday real-life VR environments and again asked to rate the level of craving elicited on a VAS (from 0 to 100), placed under each image. With this information, the software creates an exposure hierarchy combining the four VR environments with the ten foods that elicited the highest levels of food craving. Thus, there were a total of 40 three-dimensional (3D) virtual situations (10 foods x 4 VR environments) that progressed from the lowest to highest (registered) participants' scores: in the first steps of the hierarchy, participants were exposed to the foods that elicited the lowest levels of craving in each of the four VR environments, and during the final steps of the hierarchy they were exposed to the foods that provoked the highest levels of craving in the environment that provoked the highest levels of craving.

Once in the virtual situation (in all steps of the hierarchy), participants were asked to move around the scenario (using the laptop's mouse), to find the virtual table where the food was placed, and to sit down. Then, they were exposed to the food for 20 seconds. During this time, they were able to handle the virtual food using the laptop's mouse. Next, participants were asked to indicate the level of food craving and anxiety on a VAS from 0 to 100 (see also measures), displayed on the laptop's screen. Then, the participants were exposed to the following virtual situation, according to the pre-stablished hierarchy, and so on until being exposed to the 40 virtual environments. Anxiety and food-craving was assessed once in each VR situation. To increase the participant's immersion in the virtual environments, these environments were presented using stereoscopic laptops, and exposure was conducted individually in a quiet, darkened room. The evaluator/clinician also ensured that the participant's attention remained on the exposure task and, whenever necessary, reminded him/her to focus on the laptop screen. The total duration of the session was approximately 40 minutes.

Statistics

Differences in eating styles between groups were assessed by parametric (Independent-samples t-test) and non-parametric (Mann-Whitney Test) analyses, with most of the variables not fitting normality assumptions (p <.05 by the Kolmogorov–Smirnov test). Spearman's rank order correlation was performed to assess the association between mean food craving and anxiety experienced in virtual environments with scores obtained in the external, emotional,

and restraint eating subscales of the DEBQ and EDI-B, as well as demographic and other assessed variables (age, BMI and time elapsed since the last meal). Correlations were conducted separately in patients with ED and controls to explore differences between the groups. Multiple regression analyses were also conducted separately in both groups. After controlling for (exploratory purposes) the effect of potential interaction variables, i.e., time elapsed since the last meal and BMI (see results for details), external, emotional, and restrictive eating subscales (of the DEBQ) were introduced as independent variables, and food craving and anxiety were used as dependent variables. The analyses were performed to assess whether participant's eating style was a good predictor of craving and anxiety experienced during food-related VR environments. To facilitate interpretation and reduce collinearity, all variables were standardized (calculation of z-score) before conducting the correlation and regression analyses (Brendgen, Girard, Vitaro, Dionne, & Boivin, 2015; Cohen, Cohen, West, & Aiken, 2003). Standardization was conducted before joining the Spanish and Italian patients. All analyses were conducted in SPSS v.23.

RESULTS

As shown in Table 1, patients with BN and BED, as compared with healthy controls, experienced higher levels of food craving and anxiety during exposure to the VR environments. Patients also reported higher levels of external, emotional, and restrictive eating, as well as frequency/severity of binge eating behavior (assessed by the EDI-B). Large effect sizes were found in all comparisons.

Table 1. Comparison of the Healthy and the ED Group on assessed variables

	Healthy Group (n = 135)				*ED Group (n = 58)*							
	Mean	*SD*	*Median*	*IQR*	*Mean*	*SD*	*Median*	*IQR*	*U/t*	Z	*p*	*r*
DEBQ-EX	31.50	6.65	32	9	37.10	5.29	37	6	-5.683*	-	**<.001**	.380
DEBQ-EM	28.67	9.57	28	14	39.64	13.89	39	24.75	5657.00	4.90	**<.001**	.353
DEBQ-RE	20.63	7.97	20	12	29.48	10.38	25.50	18.25	5814.00	5.34	**<.001**	.384
Craving	52.03	22.89	56.10	36.53	73.28	19.91	80.19	32.46	5962.50	5.75	**<.001**	.414
Anxiety	19.65	20.99	12.42	26.43	69.21	25.13	77.19	35.41	7204.50	9.25	**<.001**	.666
EDI-B	1.92	2.13	1	3	18.10	7.13	17	10.50	7596.00	10.75	**<.001**	.776

Note: DEBQ-EX (Dutch Eating Behavior Questionnaire-External Eating), DEBQ-EM (Dutch Eating Behavior Questionnaire-Emotional Eating), DEBQ-RE (Dutch Eating Behavior Questionnaire-Restraint Eating), EDI-B

(Bulimia scale of the Eating Disorders Inventory-3), SD (Standard Deviation), IQR (InterQuartile Rank)

***T-test was conducted to assess group differences in the DEBQ-EX scale. For the rest of variables, Mann-Whitney U was used.*

The results of the correlational analyses, shown in Table 2, indicate that there were positive significant associations between food craving and external eating and time elapsed since the last meal, and negative significant association between food craving and BMI, in the healthy group, whereas in the ED group, there were positive significant associations between food craving and external eating, emotional eating and time elapsed since the last meal. In the healthy group significantly positive associations between anxiety experienced in the VR environments, time elapsed since the last meal and all the DEBQ subscales were also evidenced. In the clinical (ED) group anxiety reported in the VR environments were also positively and significantly associated with the time elapsed since the last meal, emotional and external eating.

Table 2. Non-parametric correlations (Spearman Rho) in the healthy and ED group

	Healthy Group (n = 135)				*ED Group (n = 58)*			
	Food craving		Anxiety		Food craving		Anxiety	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Age	.157	.071	.124	.155	-.189	.156	-.101	.450
BMI	-.265	**.002**	.002	.979	-.174	.191	-.110	.410
Time	.306	**<.001**	.197	**.022**	.353	**.007**	.267	**.043**
DEBQ-EM	.088	.308	.251	**.003**	.351	**.007**	.469	**<.001**
DEBQ-EX	.380	**<.001**	.319	**<.001**	.455	**<.001**	.355	**.006**
DEBQ-RES	.068	.437	.213	**.013**	.221	.096	.145	.276

Note: DEBQ-EX (Dutch Eating Behavior Questionnaire-External Eating), DEBQ-EM (Dutch Eating Behavior Questionnaire-Emotional Eating), DEBQ-RE (Dutch Eating Behavior Questionnaire-Restraint Eating), BMI (Body Mass Index), ED (Eating Disorders).

Due to the small size of the sample (specially, the ED group, *n*=58), it was not possible to conduct hierarchical multiple regressions (according to Stevens, 1996, a minimum of 15 subjects per predictor is required). Instead, several multiple regression analyses were conducted introducing the three DEBQ subscales (emotional, external, and restrictive eating styles) as independent variables for predicting food craving and anxiety. Since previous research (Ferrer-Garcia, Gutiérrez-Maldonado, Pla-Sanjuanelo et al., 2015) reported associations between BMI

and time elapsed since the last meal with anxiety, food craving, and style of eating behavior, these variables were controlled for (see appendices 1 and 2) before conducting the main multiple regression analyses. Overall, the aim was to detect potential variables that could modify the effect of eating behavior style on the dependent variable. Six multiple regression analyses were conducted in the ED and healthy groups to assess (for exploratory purposes) the potential modifying effect of BMI and time elapsed since the last meal. Each multiple regression included three predictor variables: one of the subscales of the DEBQ (emotional, external, or restrictive eating), one of the potential interaction variables (BMI or time elapsed since the last meal), and the interaction between both variables (for example, emotional eating × BMI). As shown in appendices 1 and 2 reporting the results of these multiple regression analyses, only the interaction between emotional eating and time elapsed since the last meal showed a significant effect over food craving in the ED group (Beta = -.396, t = -2.694, p =.009). Once removed the variance effect of this interaction, the effect of emotional eating over craving increased slightly. These data should be kept in mind when considering the results of the following analyses.

Table 3. Results of the multiple regression analyses for food craving in the control and ED groups

Model	Predictors	Beta	t	p	R^2	$R^2_{adj.}$	F	p	d
1	*Control Group*				.161	.141	8.361	<.001	2.104
	DEBQ-EM	-.124	-1.314	.191					
	DEBQ-EX	.435	4.914	**<.001**					
	DEBQ-RE	.029	.332	.740					
1	*ED Group*				.265	.224	6.488	.001	2.192
	DEBQ-EM	.170	1.365	.178					
	DEBQ-EX	.389	3.189	**.002**					
	DEBQ-RE	.178	1.499	.140					

Note: DEBQ-EX (Dutch Eating Behavior Questionnaire-External Eating), DEBQ-EM (Dutch Eating Behavior Questionnaire-Emotional Eating), DEBQ-RE (Dutch Eating Behavior Questionnaire-Restraint Eating)
d = Durbin-Watson statistic. Emotional, external, and restrictive eating styles were introduced as predictors. Food craving in the VR environments was the dependent variable.

Table 4. Results of the multiple regression analyses for anxiety in the control and ED groups

Model	Predictors	Beta	t	p	R^2	$R^2_{adj.}$	F	p	d
1	*Control Group*				.137	.117	6.937	<.001	2.086

	DEBQ-EM	.065	.677	.499					
	DEBQ-EX	.267	2.981	**.003**					
	DEBQ-RE	.157	1.782	.077					
1	*ED Group*				.249	.207	5.975	.001	2.048
	DEBQ-EM	.358	2.853	**.006**					
	DEBQ-EX	.249	2.019	**.048**					
	DEBQ-RE	.038	.319	.751					

Note: DEBQ-EX (Dutch Eating Behavior Questionnaire-External Eating), DEBQ-EM (Dutch Eating Behavior Questionnaire-Emotional Eating), DEBQ-RE (Dutch Eating Behavior Questionnaire-Restraint Eating)
d = Durbin-Watson statistic. Emotional, external, and restrictive eating styles were introduced as predictors. Anxiety in the VR environments was the dependent variable.

Multiple regression analyses were conducted separately in the healthy/control and clinical (ED) groups to clarify the relationship between eating behavior style and cue-elicited craving (Table 3) and anxiety (Table 4) in the VR environments. The eating style of participants accounted for 16% and 26.5% of the variation in food craving in the control and ED groups, respectively (Table 3). Interestingly, in both control and ED groups external eating was the only predictor that made a significant unique contribution to the model. The eating style of participants also accounted for comparable figures of 14% and 25% of the variation in anxiety in the control and ED groups, respectively (Table 4). In the control group, external eating was the only predictor that made a significant unique contribution to the model. In the ED group, both emotional and external eating made statistically significant individual contributions to the model, though emotional eating made a greater contribution.

DISCUSSION

The main objective of this study was to analyze the relationship between eating behavior styles, and self-reported food craving and anxiety to food-related virtual environments in BN and BED patients and healthy participants. Consistent with the cue-reactivity theory (Schachter, 1971), a positive relationship was found between the external eating style and food craving experienced in VR environments in the healthy/control and clinical (ED) groups. These results support previous research that also found higher levels of food craving in individuals (both healthy and with ED) with heightened reactivity to food cues (Brockmeyer et al., 2015; Ferrer-Garcia, Gutiérrez-Maldonado, Pla-Sanjuanelo et al., 2015). In their research, van Strien et al. (2009) stated that responsiveness to food cues may be a general characteristic of humans

linked to Neel's thrifty genotype hypothesis. According to Neel (1962), there is a genetic predisposition to fatten rapidly during times of feast to better survive during times of famine, which is a characteristic inherited from the Paleolithic era. Emotional eating, a frequently cited antecedent of binge eating (Dakanalis et al., 2014; Van Strien & Ouwens, 2007), was also positively associated with food craving in the ED group. However, when emotional eating was considered in conjunction with the other eating styles as predictors of craving, only external eating made a significant unique contribution to the model, as discussed below.

The results provide support to our first and second hypotheses. Specifically, in addition to the positive association between the external eating style and food craving experienced in the VR environments, this association was stronger in participants with BN and BED that in healthy controls. Furthermore, in agreement with our third hypothesis, participants' eating behavior style accounted for a considerable percentage of the craving experienced in the virtual environments, especially in the ED group, with external eating being the only predictor that made a significant contribution to explaining cue-elicited craving in both the control and ED groups. Burton et al. (2007) reported external eating to be the main predictor of craving in a healthy sample comprising men and women. Our results are also consistent with a previous study showing that, in a mixed sample of participants with and without EDs, external eating was the best predictor of food craving in VR environments (Ferrer-Garcia, Gutiérrez-Maldonado, Pla-Sanjuanelo et al., 2015). By also taking into account the results obtained in this study, we can draw two main conclusions. First, eating style seems to play a more decisive role when explaining food craving in patients with BN and BED than in participants without EDs. Second, when exposed to highly palatable food, external eating is probably the best predictor of craving. Consistent with Herman and Polivy's (2008) distinction between normative and sensory external cues, people who overeat in response to external cues (external eating) are especially sensitive to sensory food cues (i.e., highly appetizing and palatable). In the present study, participants were exposed to three-dimensional representations of foods that they had previously rated as producing the highest levels of desire to eat (e.g., highly palatable food). Thus, the external eating style acquires a more prominent role in such conditions.

Anxiety experienced during exposure to virtual food was also assessed in this study. A positive relationship was found between the external eating style and anxiety experienced in the VR environments, consistent with our fourth hypothesis. However, in contrast to our fifth hypothesis, this relation was similar in both the ED and control groups. Moreover, anxiety was significantly correlated with all eating styles assessed in the control group, but only with

emotional and external eating in the ED group. Although the relationship between emotional eating and anxiety has been studied previously (Goossens, Braet, Van Vlierberghe, & Mels, 2009; Mensorio et al., 2017), no attention has been deserved on the relationship between external eating and food-cue elicited anxiety, so far. Our results are, therefore, exploratory. The association between higher levels of emotional and external eating and higher levels of reported anxiety during exposure to food could, for example, be explained by anticipatory anxiety. According to the model proposed by Martínez-Mallén et al. (2007), exposure to highly palatable food may lead to anticipation of the risk of overeating and increase anxiety experienced by participants, but research lending credence to this suggestion is required. Concerning our sixth hypothesis, results revealed that external eating style predicted anxiety experienced during exposure to virtual food cues. However, while external eating was the only predictor of anxiety in the healthy/control group, the best predictor of anxiety in the ED group was emotional eating, though external eating also had a significant contribution. Again, the association between emotional discomfort and overeating behaviors in high emotional eaters probably explains anxiety responses for those with BN or BED when exposed to palatable or binge-related food cues, but further research in this area is required.

In summary, the results of this study extend the available evidence supporting the relationship between eating style and psychophysiological responses (craving and anxiety) to food-cue exposure. In controls without pathological eating behaviors, external eating was the only predictor of reported cue-elicited craving and anxiety. In participants with BN and BED, external eating was also the only predictor of cue-elicited craving, while emotional and external eating were predictors of cue-elicited anxiety, though emotional eating made a greater contribution. Finally, the study provides evidence of the ability of virtual food in virtual environments to generate these responses and detect differences between ED and non-ED groups.

Some limitations of this study should be mentioned. First, the ED sample was small, so the role of potential interaction between eating styles and other variables could not be considered in the regression analyses. To mitigate this limitation, several multiple regression analyses were conducted in both groups to control for the potential modifying effect of BMI and time elapsed since the last meal on eating style when predicting food craving and anxiety. Although useful, this solution is not perfect, as raises the probability of type II error. Consequently, this is something that should be kept in mind when construing the results. Second, control group is 10 years younger than ED group (mean age of 23.4 and 33.9,

respectively). Despite the fact that age was not significantly associated with reported food craving and anxiety in this study, previous research has suggested that the levels of experienced food craving decrease in elderly (Pelchat, 1997). Third, the percentage of male participants was very low compared with the percentage of female participants. Consequently, sex differences could not be considered, which is important because previous studies have shown higher levels of food craving in women than in men (Cepeda-Benito, Fernandez, & Moreno, 2003; Weingarten & Elston, 1991). However, Burton et al. (2007) found that this difference was specific for sweet foods, but not for other kinds of food. Likewise, sex differences have also been observed in eating behavior patterns, with women usually reporting higher levels of emotional and restraint eating styles while men report higher levels of external eating (Burton et al., 2007; Delahanty, Meigs, Hayden, Williamson, & Nathan 2002; Neumark-Sztainer, Sherwood, French, & Jeffery, 1999; Waller & Matoba, 1999). Future research should address these differences. Finally, given the cross-sectional nature of the study, causal conclusions cannot be drawn.

Despite these shortcomings, eating behavior style, especially external eating, should be considered when designing proper interventions for EDs characterized by binge eating, i.e., BN and BED. Given that external eaters are more sensible to obesogenic environment, CET may help them to reduce reactivity to food-related cues and, hence, the probability of bingeing. Once proved that VR-based exposure is a suitable method to induce food-craving in external eaters with ED, VR-based CET could be proposed to enhance the efficacy of CBT in patients with high levels of external eating and to overcome logistical problems previously encountered with in vivo CET. Although some studies have reported difficulties with virtual food inducing psychophysiological responses in participants (Ledoux et al., 2013), most of research supports its suitability (Agliaro-López et al., 2014; Ferrer-Garcia et al., 2013; Ferrer-Garcia, Gutiérrez-Maldonado, Treasure et al., 2015). Indeed, Boswell and Kober (2016) recently showed that reactivity to visual food cues (e.g., pictures and videos) was as strongly predictive of eating behavior as reactivity to real food cues, and that visual cues were more strongly predictive than olfactory cues. Future research should test whether VR-based CET is especially effective in patients with an external eating style.

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