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Research report

The relationship between fat mass, eating behaviour and obesity-related psychological traits in overweight and obese individuals ☆

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ABSTRACT

Behavioural and psychological factors related to eating have been associated with obesity, although their relationship to anthropometric measures, more specifically fat mass, has not been fully examined. This study examined the relationship between fat mass ($n = 98$; 75M, 23 F) and behavioural measures of eating and obesity related psychological traits ($n = 337$; 226M, 111 F) in overweight and obese individuals (Mean BMI 30.5 ± 4.0; BMI range 25–46 kg/m^2). Two sets of principal component analyses (PCA) were performed: one on validated questionnaires of eating behaviour and psychological traits and a second on fat mass and body weight related anthropometric measures (BMI, weight) and the aforementioned questionnaire measures. From the initial PCA ($n = 337$), the primary principal component, P1 (R^2 value of 0.33), represented a latent variable associated with overeating or binge eating behaviour. In a second PCA (questionnaire measures augmented by anthropometric variables, $n = 98$), a single component was identified, P1$^+$ (R^2 of 0.28), similar to that identified as P1 in the previous analysis and this component was highly correlated with fat mass ($\rho = 0.68$). These findings suggest that levels of body fat and eating behaviour (namely, binging or overeating) are strongly related and, at least in a subgroup of individuals, obesity may be driven by behavioural factors associated with eating in combination with pre-existing environmental and genetic factors.

Introduction

Obesity is one of the most prevalent disorders in western society and represents a major public health problem. Obesity is often described as an "epidemic" that is increasing in prevalence and is currently estimated to affect up to 33% of the United States adult population (Ogden, Yanovski, Carroll, & Flegal, 2007). In combined numbers from 10 European countries, 16% of men and 18% of women are obese (Meisenere, 2008) while in the United Kingdom 61% of the population can now be classified as overweight or obese (UK Obesity Statistics, 2010). It is generally accepted that overconsumption of food, specifically highly processed, heavily marketed, strongly obesogenic foods, is a major cause of current obesity levels (Kessler, 2009). Despite this abundant availability of obesogenic foods and aggressive marketing by the food industry, not all people become obese; some remain lean, suggesting that certain individuals are susceptible to weight gain and others are resistant (Blundell & Cooling, 2005; Hetherington, 2007). It has been proposed that there are biological differences between these groups of individuals and that lean people manage to stay this way through mechanisms that are influenced by heritable differences in neurobehavioural traits influencing eating behaviour such as hunger, satiety, response to food cues and hedonic effects of food (O'Rahilly & Farooqi, 2008). In addition, psychological traits commonly associated with obesity such as reward sensitivity and impulsivity are thought to play a role (Davis, 2009). The current epidemic of obesity has also highlighted the importance of body composition in understanding the metabolic consequences of energy imbalance. Excessive fat mass is considered to play a critical role in the metabolic dysregulation that leads to diseases such as type 2 diabetes mellitus, dyslipidemia and hypertension (Chuang et al., 2012; Napolitano et al., 2008). However, alterations in muscle mass may also contribute due to its role in glycaemic regulation through insulin-stimulated glucose disposal (Napolitano et al.,

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Conflict of interest: All authors are employees of GlaxoSmithKline and are involved in the development of anti-obesity drugs that alter eating behaviour.

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2008). In order to improve treatment regimens and optimise drug development to combat this rising tide of obesity, the identification of significant predictors of susceptibility to gain weight and the resistance to lose weight is of vital importance. The study of the relationship between body composition, particularly fat mass, neurobehavioural and psychological traits may provide the answers.

Previous work has identified relationships between anthropometric measures (i.e. body weight, body mass index (BMI)) and eating behaviour/psychological traits (Davis, 2009; Davis & Fox, 2008; Dykes, Brunner, Martikainen, & Wardle, 2004; Hays et al., 2002). Within this research, studies that have examined the relationship between behavioural factors and obesity suggest that binge eating or over eating behaviour, either in combination with or independent of, a susceptibility to periodic disinhibition of control over eating (disinhibition), are key components of obesity in a subgroup of individuals (Bryant, King, & Blundell, 2008; de Zwaan, 2001; de Zwaan & Mitchell, 1992; Stunkard, Grace, & Wolff, 1955). A review of studies in obese patients suggests that a high frequency of binge eating occurs in 23–46% of those patients seeking treatment for weight reduction (Yanovski, 2003); two-thirds of obese binge eaters report the onset of binge eating prior to obesity (Wilson, Nonas, & Rosenblum, 1993) and there is a significant association between binge eating and extreme obesity (BMI >40 kg/m^2) (de Zwaan, 2001). Amongst psychological traits, it has been suggested that high impulsivity and reward responsiveness play a prominent role in the development and maintenance of obesity (Davis, 2009). Besides the aforementioned studies, a significant body of research has attempted to delineate the psychological correlates of excess weight (for review see Friedman & Brownell, 1995; McGuire, Jeffery, & French, 2002). These studies identified several psychological consequences of obesity that can occur in some individuals and their relationship to eating behaviour (i.e. binge eating) but the relationship between eating related behavioural measures or psychological traits commonly associated with obesity and anthropometric measures, namely fat mass, have not yet been fully characterised.

However, an outstanding issue with this body of research lies in the fact that individuals can have a wide range of body composition types for similar body weights and body mass indices. Also, body mass and BMI though being simple, accurate, and precise measures, cannot elucidate changes in the discrete components of body composition. As such, these parameters are poor indicators of the amount of fuel-burning tissue (muscle) and fuel storing tissue (fat) (Heymsfield, Scherzer, Pietrobelli, Lewis, & Grunfeld, 2009; Okorodudu et al., 2010) and their relationship with eating behaviour traits may not be as robust as more sensitive measures of body composition i.e. fat mass. Utilising increasingly sensitive imaging measures and the appropriate eating behaviour measures may provide more accurate predictors of susceptibility to gain weight and to resistance to losing weight. In order to explore this hypothesis further, our behavioural and anthropometric data were analysed using principal component analysis (PCA). PCA is a dimensionality-reduction method for related multivariate analysis and can be useful to study multiple correlated phenotypes (He et al., 2008). PCA was selected as a methodology ahead of factor analysis because firstly it does not rely on normally distributed variables to be valid, and secondly does not require a (somewhat subjective) choice of rotation method. These analyses were carried out in two stages:

1. PCA to explore the degree of association and commonality purely within the behavioural questionnaires ($n = 337$).
2. PCA including both anthropometric and behavioural measures to identify common components, and learn which behavioural measures are most strongly correlated with these common components ($n = 98$).

This two-step procedure was applied with the intention of gaining the maximal understanding of the underlying relationships between the questionnaires from the full data set, before applying this knowledge to the data set including fat mass and other anthropometric measures. To capture the behavioural and psychological data we used questionnaires that represent some of the most frequently used and well validated instruments in the obesity/eating behaviour literature and these questionnaires are outlined in more detail in the methods section. In addition, we utilised a novel methodology to measure fat mass, that is, a recently developed instrument that uses the differences in the nuclear magnetic resonance properties of hydrogen atoms in organic and non-organic environments to fractionate signals originating from fat, lean tissue and free water (Taicher, Tinsley, Reiderman, & Heiman, 2003). This quantitative magnetic resonance (QMR) instrument, Echo-MRI, (Echo Medical Systems, LLC, Houston, TX) offers unrivalled precision in the measurement of body composition in animals, and has up to triple the precision for measuring body composition changes in humans compared to other regularly used methods (Napolitano et al., 2008). Accordingly, in an attempt to delineate the relationship between fat mass and behavioural measures of eating and psychological traits commonly associated with obesity, to possibly provide novel approaches for the treatment of obesity, this study examined the relationship between these variables in a cohort of overweight to obese individuals.

Methods

Participants

Three hundred and thirty-seven otherwise healthy, overweight and obese participants (226 males, 111 females) aged between 18 and 71 years (mean age = 41.6 ± 10.3 years) were recruited for this study. All participants had a body mass index (BMI) of greater than or equal to 25 kg/m^2 (mean = 30.5 ± 4.0; range 25–46 kg/m^2). Participants were recruited from the general population of the Cambridge, UK area through local newspaper and radio advertisements and were considered for inclusion if they had no personal or family history of psychiatric disorders, had no history of substance abuse, had no history of head injury or neurological disorders based on screening investigations, physical examination and a semi-structured clinical interview by a medical physician. All participants gave written informed consent for participation in the study, which was approved by the Local ethics committee.

Procedure

This study involved only medical and behavioural screening, which consisted of a single study visit for screening and enrolment onto the Clinical Unit Cambridge (CUC) volunteer panel. The study was conducted at GlaxoSmithKline, CUC, Addenbrookes Centre for Clinical Investigation, Cambridge, UK. Participants arrived at the unit and exclusion criteria were assessed during a semi-structured interview with a physician and they then underwent basic medical screening (ECG, Vital Signs, medical history and safety bloods), anthropometric measurement (height, weight, body composition analysis) followed by completion of five questionnaires related to eating behaviour and personality traits. The Echo-MR facility for measurement of body composition within the CUC was in use for other projects during a large part of data collection; consequently only 98 participants (29%) had body composition measured. Summary statistics for demographic and anthropometric measures are given in Table 1, and for behavioural measures of eating and psychological trait questionnaires in Table 2.

Table 1
Demographic and anthropometric measures of the current study population.

	Total population			Females			Males			Subset with fat mass measures		
	N	Mean	SD	*N*	Mean	SD	*N*	Mean	SD	*N*	Mean	SD
Age (years)	337	41.6	10.3	111	43.2	10.6	226	40.8	10.1	98	40.5	10.4
Weight (kg)	337	92.7	14.6	111	85.0	13.9	226	96.4	13.4	98	92.9	14.4
BMI (kg/m^2)	337	30.5	4.0	111	31.5	4.7	226	30.0	3.5	98	30.2	4.2
Fat mass (kg)	98	27.6	10.8	23	36.5	10.5	75	24.9	9.3	98	27.6	10.8
Fat-free mass (kg)	98	65.3	11.5	23	50.5	7.2	75	69.9	8.3	98	65.3	11.5

Questionnaires

The questionnaires used in this study were selected as they represent some of the most frequently used and well validated instruments in the obesity/eating behaviour literature. They were categorised into those that assess (a) behavioural aspects of eating and (b) psychological traits.

Behavioural measures of eating

Three Factor Eating Questionnaire (TFEQ) (Stunkard & Messick, 1985). This is a 2 part, self administered, 51 question assessment that measures 3 dimensions of eating behaviour thought to be aberrant in eating disorders and obesity. The TFEQ provides combinatorial score outputs for cognitive restraint in eating (cognitive restraint), susceptibility to periodic disinhibition of control over eating (disinhibition) and perceived hunger (hunger). The TFEQ has been used widely in studies of eating behaviour in obese, overweight and normal weight individuals (Lindroos et al., 1997; Yeomans, Leitch, & Mobini, 2008) and has also been shown to be sensitive to anti-obesity treatments (McElroy et al., 2006).

Binge Eating Scale (BES) (Gormally, Black, Daston, & Rardin, 1982). This is a 16 item, self administered instrument assessing behaviours (eating large amounts of foods) feelings and cognition (loss of control, guilt, and fear of being unable to stop eating) during binge eating. The scale provides a cumulative score output, with higher scores indicating increased binge eating and it has been proposed as a rapid screening instrument for binge eating behaviour in obese patients (Freitas, Lopes, Appolinario, & Coutinho, 2006). The BES has also been shown to be sensitive to anti-obesity treatments (McElroy et al., 2006; Smith et al., 2007).

Yale-Brown Obsessive Compulsive Scale (Goodman et al., 1989), (modified for binge eating (Y-BOCS-BE)) (McElroy et al., 2003). This is a 10 question (multiple-choice) self report instrument providing a cumulative score output designed to rate the presence and severity of obsessive thoughts and compulsive behaviours typically related to binge eating. The YBOCS-BE is a validated measure of behaviours related to binge eating, has been shown to be sensitive to anti-obesity treatment (McElroy, Kotwal, Hudson, Nelson, & Keck, 2004; McElroy, Kotwal, Hudson, Nelson, & Keck, 2007; McElroy et al., 2003, 2006) and is used in this study alongside the BES in an effort to gain further insight into binge eating thoughts and behaviours that may relate to body composition.

Psychological traits

Behavioural Inhibition/Activation Scale (BIS/BAS) (Carver & White, 1994). This is a 24 question self administered instrument that assesses three personality measures related to reward sensitivity/behavioural activation (BAS) and one related to behavioural inhibition/anxiety (BIS). The BIS scale is thought to measure the activity of the behavioural inhibition system which mediates responses to conditioned signals of punishment. The BAS scales assess one's persistent pursuit of desired goals (BAS drive), the inclination to seek out new rewarding situations (BAS fun seeking), and positive anticipation of rewarding events in the future (BAS reward responsiveness). These BAS subscales have been used as a marker of sensitivity to reward which may play a role in the risk profile for overeating and weight gain in certain individuals (Beaver et al., 2006; Davis, 2009).

Barratt Impulsiveness Scale (BIS 11) (Patton, Stanford, & Barratt, 1995). Impulsivity refers to behaviour that is performed with little or inadequate forethought. The BIS-11 is a 30 item self report instrument of impulsiveness and can discriminate 3 second order factors – motor impulsiveness, non-planning impulsiveness and attentional impulsiveness. Elevated impulsivity scores on

Table 2
Behavioural measure of eating and psychological trait questionnaire scores and sub-scale scores. Barratt Impulsiveness Scale (BIS-11), Three Factors Eating Questionnaire (TFEQ), Binge Eating Scale (BES), Yale-Brown Obsessive Compulsive Scale modified for Binge Eating (Y-BOCS-BE) and the Behavioural Inhibition/Activation Scale (BIS/BAS).

	Total population			Females			Males			Subset with fat mass measures		
	N	Mean	SD	*N*	Mean	SD	*N*	Mean	SD	*N*	Mean	SD
BIS-11	337	64.7	10.5	111	66.0	10.8	226	64.1	10.4	98	63.3	9.3
Attentional	337	16.2	3.6	111	16.4	3.6	226	16.0	3.6	98	15.7	3.1
Motor	337	24.0	4.4	111	24.5	4.6	226	23.8	4.3	98	23.5	3.8
Non-planning	337	24.6	5.0	111	25.1	4.9	226	24.3	5.0	98	24.2	5.1
TFEQ	335	23.5	8.6	110	29.1	7.8	225	20.8	7.5	98	22.6	8.9
Cognitive restraint	335	7.5	4.5	110	10.0	4.3	225	6.3	4.1	98	7.3	4.6
Disinhibition	337	8.7	4.0	111	11.0	3.7	226	7.5	3.7	98	8.1	3.8
Hunger	337	7.3	3.8	111	8.1	3.9	226	6.9	3.7	98	7.2	3.9
BES	337	13.5	8.8	111	19.1	9.6	226	10.7	6.9	98	12.9	9.1
YBOCS-BE	337	9.2	7.2	111	11.6	7.4	226	8.0	6.8	98	8.0	6.9
Compulsion	337	4.2	3.7	111	5.2	3.9	226	3.7	3.4	98	3.6	3.3
Obsession	337	5.0	3.7	111	6.3	3.7	226	4.4	3.5	98	4.4	3.8
BIS/BAS	337	55.9	7.6	111	57.0	7.7	226	55.4	7.5	98	58.5	6.7
BIS	337	18.6	2.6	111	18.7	2.8	226	18.6	2.4	98	19.7	2.8
BAS reward responsiveness	337	14.8	3.2	111	15.0	3.2	226	14.7	3.2	98	16.7	2.1
BAS fun seeking	337	11.0	2.3	111	11.1	2.3	226	11.0	2.4	98	11.1	2.6
BAS drive	337	11.5	2.4	111	12.1	2.4	226	11.2	2.3	98	11.0	2.3

self-report questionnaires have been reported in substance use and eating disorders (Dawe & Loxton, 2004) and impulsivity has been suggested to be related to obesity and binge eating behaviour (Davis, 2009).

Echo Magnetic Resonance Imaging – Adult Human (Echo-MRI-AH). Total fat mass, lean mass and total body water were recorded using a quantitative magnetic resonance-based method for measuring body composition directly, namely Echo Magnetic Resonance Imaging (Echo-MRI – EchoMedical Systems Inc, Houston, TX, USA). The measurement of total body fat and body composition analysis by Echo-MRI-AH was a non-invasive procedure and did not require participants to undress (shoes or metal objects, such as belts and glasses, were removed). Before each set of measurements the subject was asked to empty their bladder. The subject sat on a sliding trolley and was pushed into the bore of the magnet (the patient space is $3.6 \times 0.75 \times 0.65$ m) for approximately 2–3 min. Because the Echo-MRI-AH machine uses a low field strength magnet (static magnetic field ~0.0065 Tesla), participants were screened to ensure that they did not contain ferromagnetic objects that could distort the magnetic field. All scans for the study were performed in triplicate with the subject remaining in the instrument throughout, and the mean of the three measurements was used for analysis.

Statistical analysis

Prior to analysis BES total score and the two YBOCS-BE components (compulsion and obsession) were transformed to improve their normality ($10\log(x + 0.5)$). No transformation was identified to improve normality of other scores so they were not transformed. Fat-free mass was calculated as weight - fat mass. Gender was coded as 1 for females and 0 for males. All statistical analyses were conducted with the software SIMCA-P+(version 11.5). This provided estimates of R^2 (the fraction of the variance explained by the component) and Spearman's rho (ρ) (the correlation between the component and the measured variables). The n-th component was considered significant if the ratio $PRESS_n/SS_{n-1}$ was less than 1, where $PRESS_n$ is the prediction error sum of squares for the current component calculated by leave-one-out cross-validation, and SS_{n-1} is the residual sum of squares for the previous component.

Results

For the first PCA the dataset comprised the 13 scores/sub-scores from the five questionnaires from all 337 participants. The first two principal components were found to be significant, with R^2 values of 0.33 and 0.15 respectively, hence cumulatively explaining almost half of the variation in the dataset. Figure 1 shows the two-dimensional loadings plot (correlation scaled). The first component (P1) showed strong correlations ($\rho > 0.7$) with five behavioural measures: TFEQ-disinhibition, TFEQ-hunger, BES, YBOCS-BE obsession and YBOCS-BE compulsion. P1 was positively correlated with all 13 sub-scores. The second component (P2) was most strongly correlated with BAS reward responsiveness ($\rho = 0.76$), and moderately correlated with the other three BIS/BAS sub-scales (range $\rho = 0.54–0.66$). P2 was negatively correlated (though very weakly, range $\rho = -0.13–0.28$) with the five sub-scales which correlate most strongly with P1. Similar results were observed when the analysis was run on the two subsets of 111 females and 226 males, suggesting the gender imbalance of the current sample did not influence results.

The second PCA included data from 98 participants. The 13 behavioural scores were augmented by six anthropometric/demographic variables: body weight, fat mass, BMI, fat-free mass, age and gender. A single component was identified as significant from this analysis, with an R^2 of 0.28. Figure 2 shows the loadings plot (correlation scaled) for this component ($P1^+$). The component appears to be the same as that identified as P1 in the previous analysis, in that it was highly correlated with the same five behavioural sub-scores. Although a second component was not identified as significant, this is probably due to reduced power in the smaller sample-size since the differences in the variables between the populations are small (Tables 1 and 2).

The anthropometric measure most highly correlated with $P1^+$ was fat mass ($\rho = 0.68$). Additionally gender and BMI showed moderate positive correlations ($\rho = 0.57$ and $\rho = 0.56$ respectively) and fat-free mass a weak, negative correlation with $P1^+$. Body weight had a weak positive correlation with $P1^+$ ($\rho = 0.32$), likely due to the different weight range for females and males. This is borne out by analyses on the separate subsets of 23 females and 75 males (from the 98 individuals with body composition measurements and questionnaire data), where the correlation of weight with $P1^+$ is above 0.6 in both cases (data not shown).

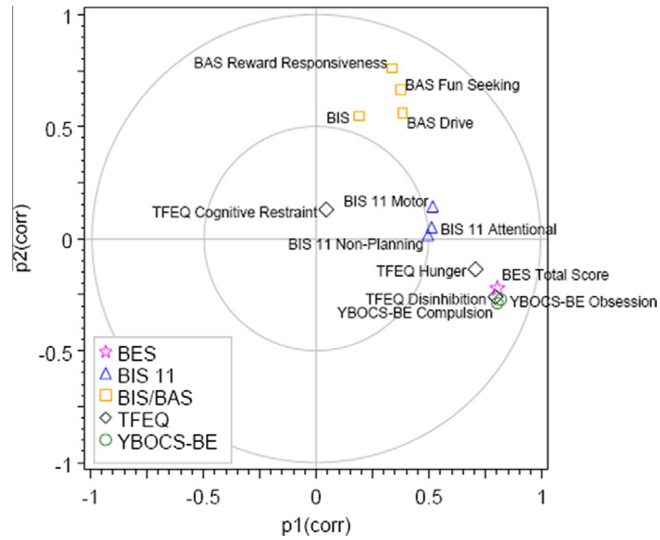

Fig. 1. Loadings plot (correlation scaled) for PCA of eating behaviour and psychological trait questionnaire sub-scales: p1(corr) denotes the first principal component which represents an overeating/binge component which explained 33% of the sample variance and p2(corr) denotes the second component representing a reward sensitivity component which explained 15% of the sample variance. Barratt Impulsiveness Scale (BIS-11), Three Factors Eating Questionnaire (TFEQ), Binge Eating Scale (BES), Yale-Brown Obsessive Compulsive Scale modified for Binge Eating (Y-BOCS-BE) and the Behavioural Inhibition/Activation Scale (BIS/BAS).

Discussion

In this study we examined the relationship between behavioural measures of eating, psychological traits commonly associated with obesity and fat mass. More specifically we first examined commonalities between measures often used in the obesity and eating behaviour literature by combining questionnaires which assess eating behaviour (Y-BOCS-BE, BES, TFEQ) and those which assess psychological traits commonly associated with obesity (BIS-11 – impulsivity and BIS/BAS – reward sensitivity) into a principal components analysis (PCA). We then performed a subsequent PCA, consisting of the above questionnaire data and obesity related anthropometric variables with a particular focus on fat mass (weight, BMI, age and gender were also included).

The emergence of two principal components, one corresponding to binge/overeating and one corresponding to reward, from our dataset is in agreement with previous literature that found an association between binge eating behaviour, reward responsiveness and obesity (Davis & Fox, 2008; Davis et al., 2007; de Zwaan,

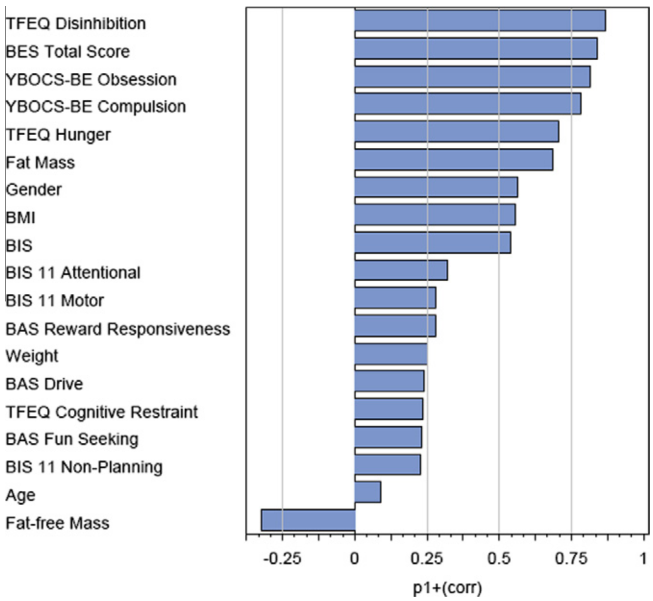

Fig. 2. Loadings plot (correlation scaled) for PCA of 13 behavioural questionnaire sub-scales with 6 demographic and anthropometric measures: p1+(corr) represents the single significant component from our second PCA. This component was highly correlated with the same five behavioural sub-scores (BES, Y-BOCS-obs, Y-BOCS-com, TFEQ-disinhibition, TFEQ hunger) from our first PCA, that is, an overeating or binge eating component. Additionally, a high correlation was observed between this binge or overeating component and fat mass ($\rho = 0.68$) and a moderate correlation between $P1^+$ and BMI ($\rho = 0.56$).

2001). It has been suggested that binge eating behaviour is a key component of obesity in certain individuals (de Zwaan, 2001; de Zwaan & Mitchell, 1992; Stunkard et al., 1955; Wilson et al., 1993; Yanovski, 2003). The emergence of a principal component, namely P1, that accounts for approximately one third of the variance in our population supports an earlier review which reported a high frequency of binge eating (or compulsive eating) in 23–46% of obese patients seeking treatment for weight reduction (de Zwaan & Mitchell, 1992). Thus it would seem that moderate to severe overeating episodes are reasonably common in the obese population, although only a minority of individuals would be expected to satisfy formal diagnostic criteria for an eating disorder (de Zwaan & Mitchell, 1992). In other words, one could hypothesise that there is a sub-population of obese patients with moderate to high scores on over-eating/binge eating rating scales, but who will not be so severely affected as to justify a diagnosis of an eating disorder. Indeed, in the current "healthy" population, participants had considerable overlap with moderate to severe scores on the BES without reporting a formal diagnosis – BES scores were in the non-binging to moderate binging range regardless of gender (mean = 13.5 ± 8.8), in males (mean = 10.1 ± 6.9) and in the moderate to severe range for females (mean = 19.1 ± 9.6). This was also true for the other measure of binge eating, the Y-BOCS-BE, with scores overall, in males and in females (mean = 9.2 ± 7.2; mean = 11.6 ± 7.4; mean = 8.0 ± 6.8 respectively) overlapping with those reported in a clinical binging population (range: 15–23; McElroy et al., 2003). It has also been postulated that an individual's sensitivity to reward can influence eating behaviour and anthropometric outcomes such as BMI (Davis & Fox, 2008; Davis et al., 2007). For example, Franken and Muris (2005) found that young women who had an increased sensitivity to reward reported increased food cravings and had increased BMI. In a similar vein, Davis et al. (2007), using structural equation modelling procedures, demonstrated that sensitivity to reward (as measured by the BIS/BAS) was related to overeating combined with a preference for sweet and fatty foods, and that these factors were positively correlated with BMI.

As the relationship between eating related behavioural measures/psychological traits and fat mass has not yet been fully characterised we performed a secondary PCA which included both anthropometric (fat mass, weight, BMI, age and gender) and the aforementioned behavioural/personality trait measures. In line with the first PCA, a single component was identified as significant from these analyses ($P1^+$) and was highly correlated with the same five behavioural sub-scores, that is, an overeating or binge eating component. Furthermore, in line with Davis and colleagues (2007), this behavioural component was highly correlated with anthropometric measures, namely BMI ($\rho = 0.56$). However, in addition, we report for the first time, a high correlation between this binge/overeating component ($P1^+$) and fat mass ($\rho = 0.68$) (Fig. 2). Recent studies have shown that participants with similar body weights and BMI can vary widely in body composition (Heymsfield et al., 2009; Okorodudu et al., 2010). Given the relationship between these anthropometric measures and eating behaviour reported previously (Davis & Fox, 2008; Davis et al., 2007; Franken & Muris, 2005), it may be the case that their relationship with eating behaviour traits may not be as robust as more sensitive measures of body composition i.e. fat mass. Indeed, the results of the current study are in line with this assumption and may have implications for the treatment of obesity. Current therapeutic approaches are at odds with the idea that obesity is a heterogeneous condition and tend to focus on environmental aspects, namely, modifying lifestyle and exercise habits. These intervention strategies, whether utilising central or peripheral pharmacological targets or behavioural approaches, have proven largely ineffective with most obese individuals losing weight for a short period but unable to maintain this weight loss over the longer term (Padwal, Li, & Lau, 2004). This lack of treatment efficacy may be as a result of the "one size fits all" approach to obesity treatment and obese patients may benefit from more personalised treatment plans. The above finding of a significant relationship between eating behaviour and fat mass suggests that particular patients could be expected to benefit from a more personalised treatment strategy, focused on their aberrant eating behaviour, when compared to other obese, non-binge or overeating individuals. Added to this, given the strong correlation between eating behaviours, namely binge eating, and fat mass, it could be that fat mass measurement is a more sensitive measure of treatment response when compared to BMI and body weight, particularly for individuals for whom overeating or binge eating is an important feature of their obesity. As such in future clinical settings, obese patients may be screened for binge eating behaviour using some or all of the questionnaires utilised in the current study to establish their binge status, then, along with their fat mass profile, an appropriate personalised treatment programme could be chosen. However, the current study is the first of many studies which are needed in this area and in particular, the findings of this study needs to be replicated in a larger sample where all participants have both eating behaviour data as well as fat mass and other anthropometric measures.

Some limitations of the current study should be noted. First there was a gender imbalance in our population of overweight and obese participants with our sample having more males than females (226 males versus 111 females). Epidemiological studies have demonstrated no gender disparity as regards the prevalence of obesity; with obesity rates generally equal in women and men (Flegal, Carroll, Kit, & Ogden, 2012). However, gender differences with regards to binge eating behaviour are less clear. In the current study, females displayed a significant correlation with self reported binge eating behaviour when compared to males ($\rho = 0.57$) suggesting that women may be more prone to binge-eating behaviour than men. While the full impact of gender on binge eating behaviour is yet to be elucidated, the associations identified in this particular study appear to be applicable to both sexes since conclusions are similar when the two sexes were analysed separately. Finally, as with many large scale studies the questionnaires administered in this investigation were self report. Use of these scales can save on time and resources but it is generally recognised that a structured or semi structured interview by a clinician or trained personnel can be of added value as many of the diagnostic criteria for eating disorders relate to behaviours that are difficult to define; for example, whether an 'objectively large' amount of food has been consumed and whether a 'loss of control' was experienced during an episode of overeating. Of the questionnaires used in this study, the BES and Y-BOCS-BE could be susceptible to this problem. For the BES, studies have assessed how this scale performs when compared to clinical interview and it has been found to be of equal value for the identification of binge eating behaviour when compared to clinical interview (Freitas et al., 2006; Gormally, Black, Daston, & Rardin, 1982). However, comparable studies have not been performed for the Y-BOCS-BE, though it has been shown to be sensitive to pharmacological treatments for BED (McElroy et al., 2003, 2004, 2006, 2007).

In conclusion, in a sample of overweight to obese individuals, we demonstrated a significant relationship between fat mass and measures of binge eating behaviour as measured by validated eating behaviour questionnaires (BES, TFEQ and Y-BOCS-BE) and a recently developed imaging tool – Echo-MRI. These findings suggest that fat mass is strongly related to binge- or over-eating and at least in a subgroup of individuals, obesity may be driven by behavioural factors associated with eating in combination with pre-existing environmental and genetic factors.

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