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The influence of personal BMI on body size estimations and sensitivity to body size change in anorexia spectrum disorders

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ABSTRACT

In this cross-sectional study, we investigated the influence of personal BMI on body size estimation in 42 women who have symptoms of anorexia (referred to henceforth as anorexia spectrum disorders, ANSD), and 100 healthy controls. Low BMI control participants over-estimate their size and high BMI controls under-estimate, a pattern which is predicted by a perceptual phenomenon called contraction bias. In addition, control participants' sensitivity to size change declines as their BMI increases as predicted by Weber's law. The responses of women with ANSD are very different. Low BMI participants who have ANSD are extremely accurate at estimating body size and are very sensitive to changes in body size in this BMI range. However, as BMI rises in the ANSD participant group, there is a rapid increase in over-estimation concurrent with a rapid decline in sensitivity to size change. We discuss the results in the context of signal detection theory.

Introduction

Anorexia nervosa (AN) is a serious psychological and physiological condition, which occurs predominantly in the female population. Current therapeutic regimes have only a limited success in treating this condition (Treasure, Claudino, & Zucker, 2010), where the long-term mortality rate has been estimated to be as high as 10% (Berkman, Lohr, & Bulik, 2007). To be able to treat this condition more effectively, we need a better understanding of its central features. Diagnostic criteria for AN include a distorted evaluation of personal body size (American Psychiatric Association, 2013), and this is also a key element of psychological models of the disorder (Cash & Deagle, 1997; Fairburn, Cooper, & Shafran, 2003). Body image distortion has been shown to be one of the most persistent of all the eating disorder symptoms, the severity of which seems to predict the long term outcome for patients (Fairburn et al., 2003; Pike, 1998). Furthermore, persistence of body image distortion has been shown to predict the rate of relapse (Channon & DeSilva, 1985; Slade & Russell, 1973) which has been estimated to be as high as 35% (Casper, Halmi, Goldberg, Eckert, & Davis, 1979). While there is evidence to suggest that women with AN under-estimate their body size (Meermann, 1983), or even show performance in size estimation tasks equivalent to non eating-disordered controls (Fernández, Probst, Meermann, & Vandereycken, 1994; Meermann, 1983), most studies have found that patients with AN overestimate their body size (Gardner & Bokenkamp, 1996; Probst, Vandereycken, Van Coppenolle, & Pieters, 1998; Slade & Russell, 1973; Tovée, Benson, Emery, Mason, & Cohen-Tovée, 2003). The disturbance in body size estimation is thought to comprise two components; a perceptual/sensory component and an attitudinal/cognitive component (Cash & Deagle, 1997). The perceptual component is described as an inability to accurately estimate body size. The attitudinal component of body image disturbance consists of dissatisfaction with body shape combined with negative attitudes to weight and shape. Moreover, there is evidence that these effects may be specific to judgements about bodies, and do not generalise to other objects such as vases (McCabe, Ricciardelli, & Ridge, 2006; Slade & Russell, 1973).

Classical psychophysics has been used to try and separate the contributions to body size estimation made by perceptual 'sensory' factors (in this case, the smallest change in body shape that the participant can detect, indexed by the difference limen, DL) and attitudinal 'non-sensory factors' (the subjective body size criterion, or bias, adopted by the participant, indexed by the point of subjective equality, PSE). For example, using the method of

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constant stimuli, in combination with the video distorting technique, Gardner and Bokenkamp (1996) reported that women with AN were more likely to over-estimate their size than non-eating disordered controls, as indexed by a higher PSE on average. On the other hand, analyses of the same data showed that the smallest difference in stimulus size (DL) that anorexic participants could reliably detect was no different from controls (i.e., both female controls and women with AN were equally sensitive at discriminating between different sized versions of their bodies). Because of this dissociation between PSE and DL, Gardner and Bokenkamp (1996) suggested that body size over-estimation is entirely due to attitudinal, non-sensory factors (see also: Gardner & Moncrieff, 1988; Mussap, McCabe, & Ricciardelli, 2008).

Recently, however, Cornelissen, Johns, & Tovée (2013) came to a different conclusion. They re-analysed a previous study in which women with AN and controls were asked to estimate their own body size by manipulating an image of themselves using a body morphing program (Tovée et al., 2003). The software allowed participants to match their perception of the size of their individual body parts with what they saw on screen by manipulating slider controls. These had the effect of changing the width and shape of those body parts. It is possible to calculate the BMI of these self-manipulated bodies from their perimeter area ratios (Cornelissen et al., 2013). As a result, Cornelissen et al. could compare directly the participants' estimates of their own BMIs with their actual BMIs. They found that the inaccuracies in body size estimation could largely be explained by a known perceptual error in magnitude estimation called contraction bias (Poulton, 1989). Critically, as shown in Fig. 1A, the relationship between estimated BMI and actual BMI appeared to be exactly the same for participants with anorexia and controls; there were no differences in the pattern of contraction bias between the two groups. This figure is a schematic representation of the results from Cornelissen et al. (2013) in which women with AN and controls used an interactive software program to estimate body size. The line of equality (i.e., perfect accuracy) is shown by the dotted black line. The control participants (whose response distribution is indicated by the cross-hatched region) varied in BMI between 14.7 and 36.8 and the women with AN (indicated by the grey region) varied in BMI between 11.5 and 18.4. The solid black line represents the regression of estimated BMI on actual BMI and has the same slope and intercept for women with AN and controls.

Contraction bias arises when one uses a standard reference or template for a particular kind of object against which to estimate the size of other examples of that object. The estimate is most accurate when estimating the size of an object of a similar size to the reference, but becomes increasingly inaccurate as the magnitude of the difference between the reference and the object increases. When this happens, the observer estimates that the object is closer in size to the reference than it actually is. As a result an object smaller in size than the reference will be over-estimated and an object larger will be under-estimated. Thus, if we use a "reference body" based on an average of all the bodies we have seen in our life to make our judgements of body size (Winkler & Rhodes, 2005), individuals with very thin bodies will over-estimate their own body size, and individuals with very large bodies will under-estimate their body size (illustrated in Fig. 1A). An earlier study by Kuskowska-Wolk and Rössner (1989) reported results on self-estimation of body size that is also consistent with a contraction bias explanation. In addition, Cornelissen et al. (2013) also found an independent, modulating effect of psychological factors, as illustrated in Fig. 1A. The thick dashed black line represents the increase in intercept for the regression of estimated BMI on actual BMI as psychological concern about body shape and weight increase (i.e., the regression line moves up the *Y*-axis as concerns increase). The contraction bias explanation predicts that for both controls and women with AN, the accuracy of their body size estimation will be driven by the BMI of the participants. Cornelissen et al. report that this is the case, but the BMI values of the women with AN in the study by Tovée et al. (2003) all actually fell within a relatively narrow range of 6.9 BMI units (11.5–18.4). Most of the variation in BMI in this study is based on the responses of the control participants who ranged in BMI between 14.7 and 36.8 (22.1 BMI units). Cornelissen et al.'s (2013) assumption is that with a wider BMI range (including recovering patients to expand the range), the responses of the women with AN should follow the same pattern as the control participants. This is illustrated in Fig. 1B, where the white arrow shows how the regression of estimated BMI on actual BMI in these women should track up along the same regression line as in Fig. 1A when BMI increases. In short, this model predicts that as BMI increases in women with AN, so body size over-estimation should *decrease*.

Alternatively, it is entirely possible that psychological factors represent a stronger driving force behind body size over-estimation in women with AN than they do for controls. If so, this could lead to a different outcome. Consistent with this possibility, an individual's body size (as indexed by BMI) is known to be strongly correlated with body dissatisfaction (Gardner, Brown, & Boice, 2012; Stice & Shaw, 2002; Striegel-Moore et al., 2004). Women with AN who have achieved a very low BMI might be expected to have relatively low body size concerns, but during the recovery process as their weight increases, their body size concerns would rise in parallel. Therefore, an alternative outcome for women with AN is that as their

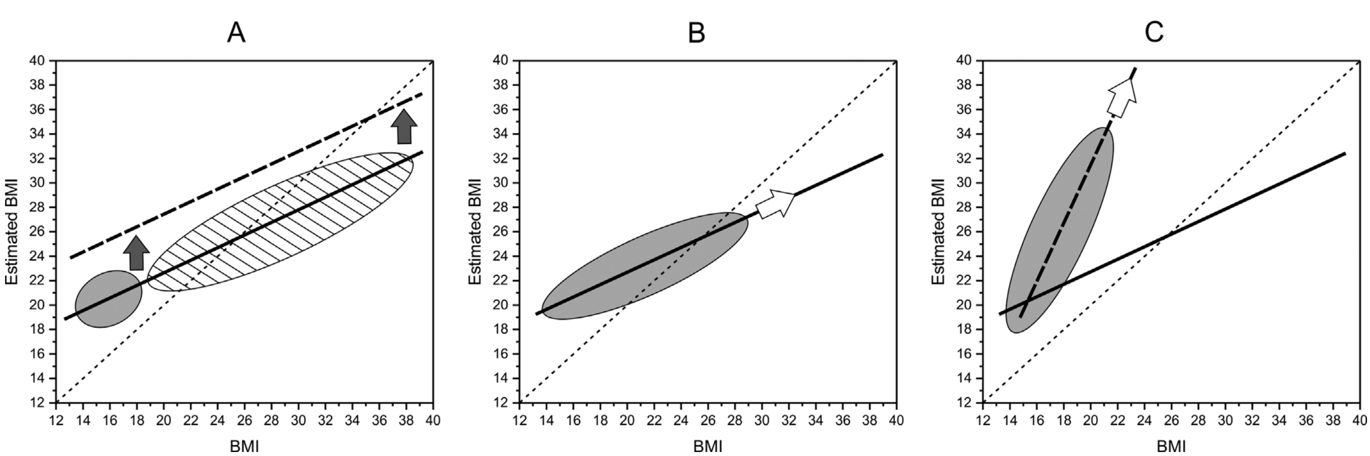

Fig. 1. (A) Schematic representation of the results from Cornelissen et al. (2013). (B) The pattern of body size estimation predicted by the contraction bias model in women with AN, or recovering from AN (i.e., in an eating disordered group with a wider BMI range). (C) The pattern of body size over-estimation predicted by increasing psychological concerns, rather than contraction bias. See text for details.

Table 1
Means and standard deviations of the characteristics of the three ANSD subgroups.

	ANSD1 ($n = 12$)		ANSD2 ($n = 20$)		ANSD3 ($n = 10$)		ANSD 1v2	ANSD 1v3	ANSD 2v3
	M	*SD*	*M*	*SD*	*M*	*SD*	*p*	*p*	*p*
Participant characteristics									
Age (years)	22.42	3.65	25.80	7.62	22.36	3.44	.78	.99	.81
BMI (weight/height^2)	18.40	2.35	21.03	2.95	22.62	1.59	.12	<.01	.63
Age at onset (years)	17.42	3.92	15.55	2.01	16.45	1.97	.54	.99	.92
When treatment ended (years)	0.00	0.00	3.45	4.11	1.95	2.90	–	.23	.96
Duration of illness (years)	5.04	4.70	6.75	6.79	4.91	3.05	.99	.99	.99
Depression and self esteem									
RSE score	8.33	2.35	16.58	5.03	15.70	5.81	<.01	.02	.99
BDI score	31.91	9.49	15.74	8.10	15.00	10.46	<.01	.01	.99
Eating and body shape concern									
EAT score	39.25	15.70	21.10	13.27	28.80	15.51	.01	.72	.80
BSQ score	71.00	17.69	55.50	17.00	62.20	18.47	.16	.95	.98
EDEQ score	4.01	1.34	2.75	1.18	3.05	1.65	.09	.76	.99
EDEQ wc score	4.08	1.58	3.05	1.34	3.70	1.50	.40	.99	.92
EDEQ bs score	4.70	1.35	3.77	1.41	3.81	1.58	.50	.81	.99
Psychophysical performance									
PSE (weight/height^2)	20.57	4.93	21.95	5.26	23.66	4.15	.99	.66	.98
OE (i.e., PSE – BMI)	2.17	3.25	1.10	2.83	1.04	3.03	.99	.77	.93
DL (weight/height^2)	0.53	0.28	0.65	0.46	0.98	1.05	.97	.99	.99

Note: ANSD1: AN participants being treated at the time of testing; ANSD2: AN participants no longer being treated; ANSD3: atypical AN or Bulimia that switched to AN; BDI, Beck Depression Inventory; RSE, Rosenberg Self-Esteem Scale; EAT, Eating Attitudes Test; BSQ, Body Shape Questionnaire; EDEQ, Eating Disorder Examination Questionnaire global score; EDEQ wc, Eating Disorder Examination Questionnaire weight concern subscale; EDEQ bs, Eating Disorder Examination Questionnaire body shape concern subscale; PSE, Point of Subjective Equality; OE, over estimation; DL, difference limen.

weight increases, there is a rapid *rise* in the degree of body size overestimation reflecting their accelerating concerns about body shape and weight. This is illustrated in Fig. 1C, where the white arrow shows how the regression of estimated BMI on BMI for women with AN should follow the trajectory of the thick dashed black line.

To determine which outcome predicts the accuracy of body size estimations for women with AN, we have recruited a group of women who have all had a diagnosis of AN, but who now show significant variation in their BMI and psychological concerns. These women should more correctly be referred to as suffering from anorexia spectrum disorders (ANSD). By deliberately taking advantage of individual differences in this way, we can determine whether the accuracy of body size estimation increases or decreases as the BMI of ANSD participants varies and therefore determine the relative importance of psychological factors and perceptual bias as illustrated in Fig. 1B and C.

Method

The experimental procedures and methods for participant recruitment for this study were approved by: the local ethics committee at Northumbria University; the Beating Eating Disorders Organisation (BEAT) and the Northern Initiative on Women and Eating (NIWE) Organisation.

Participants

We recruited 42 participants into the study all of whom who have had a formal diagnosis of anorexia nervosa ($n = 34$) according to DSM-IV-R or DSM-5 (American Psychiatric Association, 2004, 2013) or bulimia nervosa followed by the onset of anorexia ($n = 8$) – it is not uncommon for patients to move between diagnostic categories (Fairburn & Harrison, 2003). Table 1 shows the details of the participants divided into 3 subgroups: ANSD1: women with a diagnosis of AN who were being treated at the time of testing; ANSD2: women with a diagnosis of AN who were no longer being treated; ANSD3: women with a diagnosis of either atypical AN ($n = 3$) or Bulimia that switched to AN ($n = 8$), 4 of whom were being treated at the time of testing. The right hand columns of Table 1 show the output of pairwise comparisons of the three subgroup means, adjusted for multiple comparisons, using the permutation method in PROC MULTEST (SAS v9.3). We acknowledge that this design is deliberately intended to look at the effect of individual differences within the anorexia spectrum, as opposed to a design in which we might compare directly between distinct eating disordered subgroups defined a priori.

In addition, 100 participants were recruited from the population of undergraduate students at Newcastle and Northumbria Universities and from the general population in and around the Newcastle upon Tyne area, all of whom consented to take part in the study as non-eating disordered controls. No control participants had a history of eating disorders. The participants displayed variation in body mass index (BMI), attitudes to eating, body shape and size, levels of depression and anxiety. For the characteristics of the control participants see Table 2.

Measures

Psychometric measurements. To assess participants' attitudes towards body shape, weight and eating we used: (1) The Eating Disorders Examination Questionnaire (EDEQ), which is a self-report version of the Eating Disorder Examination (EDE) structured interview (Fairburn & Beglin, 1994). This is commonly used as a screening questionnaire for eating disordered behaviour and has been normed for young women (Mond, Hay, Rodgers, & Owen, 2006). The questionnaire contains four subscales reflecting the severity of aspects of the psychopathology of eating disorders; the Restraint Scale investigates the restrictive nature of the eating; the Eating Concern scale to the preoccupation with food and social eating; the Shape Concern subscale investigates dissatisfaction with body shape and the Weight Concern subscale assesses dissatisfaction with body weight. The EDE-Q (range 0–6) also measures overall disordered eating behaviour. Furthermore, it provides frequency data on key behavioural features of eating disorders; (2) The Eating Attitudes Test (EAT, range 0–78; Garner & Garfinkel, 1979) which investigates eating habits and dissatisfaction with own body weight and shape. It is a subjective index of the symptoms displayed by individuals with eating disorders and the test is used as a screening questionnaire for eating disorders; (3) the 16-item Body Shape Questionnaire (BSQ, range 0–96; Evans & Dolan, 1993) which

Table 2
Means and standard deviations for the participant characteristics, separated according to whether they belong to the ANSD or the healthy control group.

	ANSD (n = 42)		Control (n = 100)		p
	M	SD	M	SD	
Participant characteristics					
Age (years)	23.80	6.05	24.02	8.91	.99
BMI (weight/height^2)	20.89	2.84	24.01	5.03	<.01
Percentage body fat	25.56	6.41	31.63	5.04	<.01
Depression and self esteem					
BDI	20.00	11.37	9.09	6.08	<.01
RSE	14.00	5.96	18.56	4.79	<.01
Eating and body shape concern					
EAT	27.38	15.55	11.07	9.08	<.01
BSQ	61.10	18.63	50.08	17.33	<.01
EDEQ	3.12	1.42	2.01	1.21	<.01
EDEQ wc	3.50	1.48	2.21	1.44	<.01
EDEQ bs	4.04	1.46	2.97	1.50	<.01
Psychophysical performance					
PSE (weight/height^2)	22.21	4.95	23.80	5.13	.36
OE (i.e., PSE – BMI)	1.41	3.04	−0.14	2.85	.04
DL (weight/height^2)	0.72	0.66	0.99	0.81	.32

Note: BDI, Beck Depression Inventory; RSE, Rosenberg Self-Esteem Scale; EAT, Eating Attitudes Test; BSQ, Body Shape Questionnaire; EDEQ, Eating Disorder Examination Questionnaire global score; EDEQ wc, Eating Disorder Examination Questionnaire weight concern subscale; EDEQ bs, Eating Disorder Examination Questionnaire body shape concern subscale; PSE, point of subjective equality; OE, over estimation; DL, difference limen.

indexes the degree of preoccupation and negative attitude toward body weight and body shape. The participants' level of depression was measured using the Beck Depression Inventory (BDI, range 0–63; Beck, Ward, Mendelson, Mock, & Erbaugh, 1961). Their self-esteem was indexed using the Rosenberg Self-Esteem Scale (RSE, range 0–30; Rosenberg, 1965).

Anthropometric measurements. The participants' body mass index (BMI) was measured with a set of calibrated scales and a stadiometer. The participants' waist, hip, under-bust and bust circumferences were measured using measuring tapes. Participants' percentage body fat was measured from skinfold thickness obtained with Harpenden Callipers. The skinfold measurements were obtained from eight sites, allowing the percentage of body fat to be calculated (Durnin & Womersley, 1974). The skinfold measurements were made by an ISAK (International Society for the Advancement of Kinanthropometry) trained and experienced investigator.

Psychophysical measurements. In this study we apply classical psychophysical methods (cf Gardner, 1996) to measure two components of the participants' judgements of body size: (a) the point of subjective equality (PSE) and (b) the difference limen (DL). The PSE is the participant's estimate of their body size. The DL is an estimate of how sensitive a participant is to changes in body size and equates to the smallest difference in body size that she can detect. To obtain these measurements, we use the method of constant stimuli in a two alternative forced choice paradigm. On every trial of the task, the participants are presented with an image of a woman and they have to respond by button press whether they believe the image to be smaller or larger than themselves. The BMI of the body varies on each presentation from smaller than to larger than the actual BMI of the participant. For each participant, we then plotted the proportion of 'larger' responses (y-axis) as a function of the BMI of the stimulus (x-axis), and fitted a cumulative Gaussian (sigmoid) curve to the data, as illustrated in Fig. 3D. The PSE is then defined from this curve as the BMI at which participants would respond 'larger' 50% of the time. Therefore, the PSE corresponds to the midpoint of the curve where, effectively, participants would be equally like to respond 'smaller' or 'larger' because a stimulus with this BMI has the same size as they believe themselves to have. The value of BMI at the PSE may be smaller (i.e., an underestimation), the same as or larger (an over-estimation) than a participant's actual BMI. The DL is the difference in the BMI of the stimuli falling between the 25% and 75% 'larger' response points (see Gescheider, 1997). This range captures the steepness of the psychometric curve. Participants who are very sensitive to small changes in body size will have a steeper psychometric function with a correspondingly small DL. It is important to emphasise that there is no necessary correlation between PSE and DL. Participants who over-estimate or under-estimate their body size may be equally likely to be sensitive (small DL) or insensitive (large DL) to changes in body size.

Stimulus image preparation. Creating stimulus images which correctly represent how body shape changes as a function of changing BMI is difficult, because these changes are highly non-linear. One method that has been used previously is the video-distortion technique (VDT) (see e.g., Gardner & Bokenkamp, 1996; Probst, Vandereycken, & Van Coppenolle, 1997) in which 2D images of people are stretched or compressed in the horizontal dimension. However, this linear method is problematic as it creates shape changes particularly in the shoulder and hip regions which tend to be unrealistic (see below). Alternative methodologies can be used, such as morphing between images of high and low BMI bodies. While this is an improvement on the VDT in principle, because it is a non-linear method, it is nevertheless extremely difficult to maintain the combination of high feature definition and stable identity of the person in the morphed images across a wide range of BMI values. Inevitably, some form of averaging or smoothing is required which reduces the realism in the resultant images. For these reasons, we instead used film industry computer-generated imagery (CGI) methods to create graded 3D images of individuals.

Fig. 2 illustrates the comparison between the VDT and CGI methods. The top row shows three CGI images from our database of stimuli. From left to right, they represent approximately BMIs 13, 17 and 21 respectively. The second row shows the body shape changes produced by applying the video distortion technique (VDT) to the central image in the first row. The horizontal compression (left image) and expansion (right image) for the images on the second row were made so that waist widths corresponded to the BMI 13 and 21 images from the top row, respectively. The third row shows the difference between the two methods of image manipulation. The grey shaded outline represents the CGI image and the dotted line the VDT image for BMI 13 (left) and BMI 21 (right). Row three shows how for thinner images, the VDT compresses the width of the hips and shoulders more than the CGI technique. In comparison,

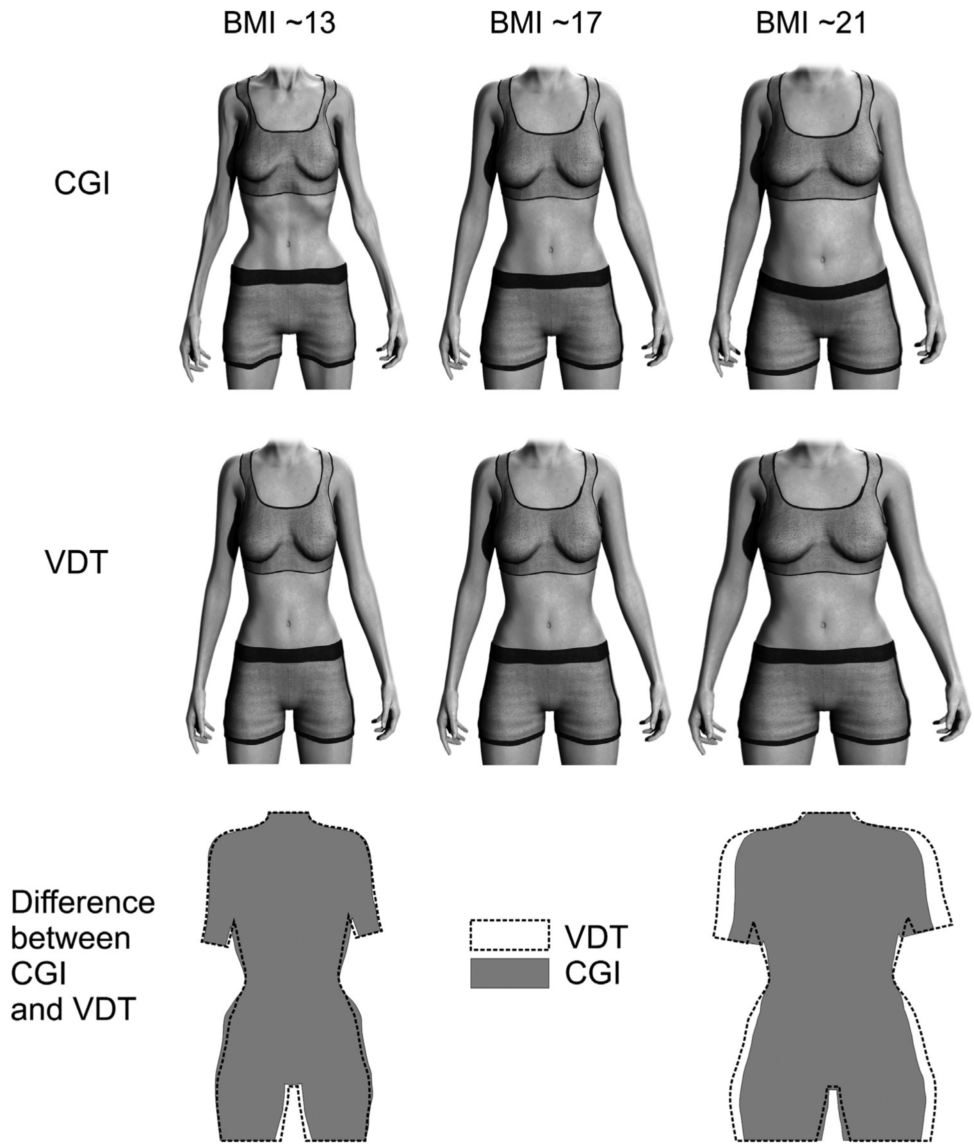

Fig. 2. The top row shows three CGI images from our database of stimuli. The second row shows the body shape changes produced by applying the video distortion technique (VDT) to the central image in the first row. The third row shows the difference between the two methods of image manipulation. See text for details.

for larger images, the VDT exaggerates the width of the hips and shoulders relative to the CGI method. In addition, the width of the gap between the thighs changes in opposite directions: consistent with reality, the CGI method shows a reduction in this gap with increasing BMI, whereas the VDT shows an increase.

Particular advantages of the CGI method are: (a) the identity of the person in the image is clearly maintained over a wide BMI range; (b) the body shape changes at different BMI levels are extremely realistic; and (c) the 3D rendered stimulus images are high definition and photorealistic. Another critical feature is that the stimuli are calibrated for BMI. We used the Health Survey for England (HSE 2003 & 2008) datasets to create calibration curves between waist and hip circumferences and height derived from ~5000 females in the UK, aged between 18 and 45. Because our CGI models exist in an appropriately scaled 3D world, having set the height of our models (1.6 m) we can therefore measure their waist and hip circumferences, and compare these with our HSE calibration curves in order to compute their BMI (Cornelissen, Toveé, & Bateson, 2009). Finally, we carried out two further qualitative checks of the plausibility of the overall body shape changes that we created in the modelling environment. First, we compared the 3D volumes and shapes from our CGI modelled bodies to a 3D statistical model of the relationship between BMI and shape changes in 114 real bodies (Hasler, Stoll, Sunkel, Rosenhahn, & Seidel, 2009). Secondly, we compared our images against a library of digital photographs of 220 women in a standard pose who varied in BMI from 11 (emaciated) to 45 (obese) (Tovée et al., 2003).

Procedure

For the presentation of stimuli, we used a Python program written by one of the authors to implement the two alternative forced choice task. Stimuli were presented on an 18″ flat panel LCD screen (1280 $w \times$ 1024 h pixel native resolution, 32-bit colour depth) for as long as it took participants to make a decision. At the standard viewing distance of ~60 cm, the CGI model subtended ~26° vertically and ~8° horizontally. Each participant first judged 7 images covering the whole BMI range (from 12.5 to 44.5 in equal BMI steps) presented in 2 separate blocks. Each stimulus image appeared 10 times in each block, and the order of presentation was randomised.

Based on the responses from each block, the participants' point of subjective equality or PSE (the BMI they believe themselves to be) was calculated automatically by fitting a cumulative normal distribution. These two values were then averaged to give an initial estimate of the participant's PSE. On the basis of this initial estimate, the program presented a further set of 21 images (spread over a range of 5 BMI units centred on the participant's initial PSE, at a spacing of 0.25 units per image) for the participants to judge. Each image was presented 10 times in randomised order. This final set of judgements allowed us to calculate a definitive estimate of PSE as well as the difference limen or DL (that is how sensitive participants are to changes in BMI).

Results

Task Reliability

The responses to the questionnaires across the sample showed good internal reliability scores. For RSE, BDI, BSQ, EAT and EDEQ, Cronbach's alpha was: .89, .93, .96, .92 and .96 respectively. For the PSE scores from the 2AFC task, we estimated reliability in two ways. First, for the entire sample, we divided the last block of body size estimation trials into a first and a second half (i.e., in time), in order to estimate split-half reliability. We carried out separate probit analyses on each half of the data to obtain a PSE estimate from each half. The correlation between the two sets of PSE scores ($r = .92$, $p < .0001$) suggests good reliability. In addition, we asked 17 participants to return to the laboratory to re-run the body size judgement task. The shortest interval for these test retest measurements was ~1 month. The Pearson correlation between PSE estimates was $r = .93$ ($p < .0001$) and a dependent samples *t*-test comparison of the means was not significantly different from zero ($M = 0.48$, $p = .333$).

ANSD Participants

As Table 1 shows, there are significant differences between the three subgroups of ANSD participants on some psychometric measures. For example, consistent with previous studies (e.g., Tovée, Emery, & Cohen-Tovée, 2000; Tovée et al., 2003), the group who are currently under treatment (i.e., ANSD1) have significantly lower BMIs, lower self-esteem, higher tendency towards depression and the most disturbed attitudes to eating compared to the other two groups (ANSD2 and ANSD3). This raises the question whether the relationships between PSE, DL and BMI in the three ANSD subgroups might be different. If so, then the distinction between the three groups should be maintained when comparing them statistically to healthy controls. Alternatively, if, for example, there are no statistically significant differences in the relationships between PSE and BMI for these three subgroups, we would gain statistical power in our analyses by treating all participants with a history of AN as one group. Therefore, we used PROC MIXED (SAS v9.3) to test whether there is a main effect of ANSD grouping on the regressions of PSE on BMI, and separately, DL on BMI. Since the distribution of raw DL scores was non-normal (Shapiro–Wilk's $W = .62$, $p < .001$) we applied a logarithmic transformation to these data. For PSE, the mixed linear model explained 71% of its variance. The Type III test of the fixed effect of BMI was significant at the specified .05 level, $F(1,37) = 67.36$, $p < .001$, but the tests for ANSD group, $F(2,37) = 0.55$, $p = .580$, and the interaction between BMI and ANSD group, $F(2,37) = 0.54$, $p = .587$, were not. For DL, the mixed linear model explained 15.8% of its variance. The Type III test of the fixed effect of BMI was significant at the specified .05 level, $F(1,37) = 7.11$, $p = .011$, but the tests for ANSD group, $F(2,37) = 1.09$, $p = .347$, and the interaction between BMI and ANSD group, $F(2,37) = 1.07$, $p = .354$, were not. Since we could find no statistically robust effects of the subgroups in these preliminary analyses, henceforth we treat all participants with ANSD as one group.

Univariate Statistics

Table 2 shows the means and standard deviations (*SD*) for the participant characteristics, separated according to whether they belong to the anorexia spectrum disorders (ANSD) or the non eating-disordered control group. The right most column of Table 2 shows the output of pairwise comparisons of these group means, adjusted for multiple comparisons, using the permutation method in PROC MULTEST (SAS v9.3). For The Eating Disorder Examination Questionnaire, a global eating disorder score was compiled across the subtests which combines the evaluation of restrictive eating behaviour, participant psychological concerns about eating, concerns about their own weight and concerns about their own body shape. Consistent with previous literature we found that when compared to non-eating disordered controls, the ANSD participants had statistically significantly lower BMIs and percentage body fat, elevated concerns about body shape, eating behaviour and body weight (EAT, BSQ, EDEQ), greater tendency towards depression, reduced self-esteem and significantly greater over-estimation of body size (OE). The relatively high mean BMI for the ANSD participants reflects that fact that an adequate test of our hypotheses *requires* this participant group to have a wide BMI range. Finally, we found no statistically significant differences between the group means for the sensitivity measure for body size estimation (DL) or chronological age.

Multivariate Statistics

We used PROC MIXED (SAS v9.3) to build a mixed linear model with estimated BMI (i.e., PSE) as the outcome variable, and actual BMI and GROUP (i.e., ANSD versus healthy controls) as predictor variables. In addition, we wanted to control for any influence of AGE and the psychometric variables (RSE, BDI, BSQ, EAT and EDEQ). In order to avoid the possibility of introducing substantial variance inflation, we first checked for evidence of co-linearity amongst the psychometric variables. Across the sample of 142 participants the Pearson correlations between RSE and BDI, RSE and BSQ, RSE and EAT, RSE and EDEQ, BDI and BSQ, BDI and EAT, BDI and EDEQ, BSQ and EAT, BSQ and EDEQ, and EAT and EDEQ were: −.75, −.61, −.62, −.57, .60, .66, .56, .72, .84 and .79 respectively. All correlations were statistically significant at $p < .001$. Given these substantial correlations, we therefore used PROC FACTOR in SAS v9.3 (SAS Institute, North Carolina, US) to carry out an iterated principal factor analysis with rotation in order to identify the significant latent variable(s) in the psychometric data. We then used the factor scores from these latent variable(s) in our statistical models. The Kaiser–Meyer–Olkin (*KMO*) measure of sampling adequacy (which indicates the degree of diffusion in the pattern of correlations) was .81 suggesting an acceptable sample. One factor had an Eigen value greater than Kaiser's criterion of 1 (i.e., 3.39) which explained 98% of the variance. The scree plot showed an inflexion, i.e., Cattel's criterion which also justified retaining just the one factor. The residuals were all small, and the overall root mean square off-diagonal residual was 0.081, indicating that the factor structure explained most of the correlations. The factor loadings for RSE, BDI, BSQ, EAT and EDEQ were: −.76, .76, .86, .86, .86 respectively. This latent variable, referred to henceforth as PSYCH, represents a combination of the attitudes thought to contribute to body size disturbance: disturbed attitudes to eating, weight, and shape, and low self-esteem and depression.

PSE. The mixed linear model for PSE explained 71% of its variance. Both ANSD and control participants showed a positive, linear relationship between actual BMI and PSE, $F(1,137) = 207.72$, $p < .001$, 95% *CI* [0.68, 0.90]. Critically, however, the pattern of estimation by women with ANSD is statistically different from that of the controls because we found a significant main effect of GROUP, $F(1,137) = 14.90$, $p < .001$, 95% *CI* [−19.08, −6.16] as well as an interaction between GROUP and BMI, $F(1,137) = 15.33$, $p < .001$, 95% *CI* [.29, .89].

Fig. 3A illustrates the outcome from the mixed linear modelling for PSE. White dots with solid white regression line and grey triangles with solid black regression line represent participants with ANSD and non eating-disordered controls respectively. The dotted black diagonal line in Fig. 3A shows the line of equality (i.e., perfect estimation) between actual BMI (x-axis) and estimated BMI (y-axis) as indexed by PSE. Data points above this line represent over-estimation, while data points below it represent under-estimation. Fig. 3A therefore shows that low BMI control participants tend to over-estimate body size; control participants whose BMI was in the mid-range were reasonably accurate, and high BMI control participants tended to under-estimate body size. The regression slope for this relationship was significantly *less* than 1, $\beta = 0.82$, $F(1,97) = 9.96$, $p < .005$, and is therefore consistent with contraction bias in the controls. Participants with ANSD, however, showed a very different pattern of results. Low BMI participants with ANSD were the most accurate at body size estimation. Thereafter, in participants with higher BMI, individuals with ANSD systematically over-estimated body size, and the magnitude of this over-estimation increased in direct proportion to increasing BMI. The regression slope for PSE on BMI in ANSD participants was significantly *greater* than 1, $\beta = 1.39$, $F(1,39) = 5.86$, $p < .05$. Clearly, this is not consistent with contraction bias, and therefore these results do not support Hypothesis 1 as outlined in Fig. 1A, but do support Hypothesis 2. Finally, we found a significant Type III test of the fixed effect of PSYCH, $F(1,137) = 17.23$, $p < .001$, 95% *CI* [0.59, 1.66] on PSE. However, we found no evidence for any two- or three-way interactions involving PSYCH. This result is illustrated in Fig. 3B. White and black regression lines represent participants with ANSD and non eating-disordered controls respectively. Dashed and solid lines represent 'high' (+1 *SD*) and 'low' (−1 *SD*) effects of PSYCH respectively. This result suggests that any participant with a greater tendency towards depressive symptoms, shape and weight concern, *irrespective of group*, was more likely to over-estimate their body size. Therefore, while the significant interaction between GROUP and BMI supports Hypothesis 2, it is unlikely that this can be attributed to psychological factors alone, because any influence of PSYCH on PSE was essentially the same for ANSD and healthy controls.

How robust is this result? To address this question, we knocked out participants one by one from the ANSD sample by systematically restricting the upper limit of the sample for BMI and refitting the model above. We retained a statistically significant effects of GROUP even when the sample size for the ANSD participants was reduced to 67% ($n = 28$) of the original 42, at a BMI cut-off of 22.3. Therefore, we suggest that our result is indeed robust. Moreover, this test of the model is considerably more stringent than applying standard regression diagnostics, because no data point in the analysis of the full sample exceeded the Cook's *D* or *DFFITS* critical values for undue influence in the model (i.e., 1 & 2 respectively). As a further check, we also re-ran the whole analysis having removed the 8 participants whose initial diagnosis was bulimia, and obtained remarkably similar, statistically robust results. For this reduced model, the Type III tests of the fixed effects of BMI, $F(1,129) = 175.33$, $p < .001$, 95% *CI* [0.68, 0.90], PSYCH, $F(1,129) = 14.40$, $p < .001$, 95% *CI* [0.50, 1.60], GROUP, $F(1,129) = 10.85$, $p = .001$, 95% *CI* [−18.03, −4.50], and the interaction between BMI and GROUP, $F(1,129) = 11.03$, $p = .001$, 95% *CI* [0.22, 0.85], were all significant at the specified .05 level.

DL. The mixed linear model for $\log_{10}$ DL explained 22.1% of its variance. Both ANSD and control participants showed a positive, linear relationship between actual BMI and $\log_{10}$ DL, $F(1,137) = 21.98$, $p < .001$, 95% *CI* [0.0068, 0.025]. However, the significant main effect of GROUP, $F(1,137) = 7.05$, $p = .008$, 95% *CI* [−1.32, −0.19] as well as the interaction between GROUP and BMI, $F(1,137) = 5.00$, $p = .027$, 95% *CI* [0.0034, 0.056] show that the pattern of estimation by women with ANSD is statistically different from that of the controls, as can be seen in Fig. 3C. White dots with a solid white regression line and grey triangles with a solid black regression line represent participants with ANSD and non eating-disordered controls respectively. The control participants only showed a modest reduction in sensitivity to the task (i.e., increasing DL) with increasing BMI. This pattern was much more dramatic for participants with ANSD: low BMI participants with ANSD showed much smaller DL values than controls with similar BMI, suggesting very high sensitivity to the task. As the BMI of participants with ANSD increased, DL increased steeply towards the values of control participants, at a BMI of ∼26. Finally, we did not find an effect of PSYCH, $F(1,137) = 0.75$, $p = .389$, 95% *CI* [−0.026, 0.067] on $\log_{10}$ DL.

In summary, the results for PSE and DL suggest significant differences in the perceptual aspects of body size estimation when participants with ANSD and non-eating disordered controls are compared. Moreover, the particular pattern of differences in participants with ANSD depends on the BMI of the observer: very accurate and sensitive body size estimation at low BMI, but large over-estimation with low sensitivity at high BMI.

Discussion

The aim of the current study was to investigate the relationship between BMI, body size estimation and psychological status in women who have had a diagnosis of anorexia nervosa and compare their responses to those of non eating-disordered controls. Based on prior literature, we predicted two possible outcomes. According to the contraction bias model (Fig. 1B), increasing BMI in women with ANSD should lead to *reducing* body size over-estimation, because their judgements should follow the same trajectory with increasing BMI as has been shown for non eating-disordered controls. In contrast, based on studies which report strong positive correlations between BMI/body size and psychological concerns about body shape and weight, Fig. 1C illustrates an opposing prediction: that body size over-estimation should *increase* systematically with increasing BMI.

In our control participants, the accuracy of body size estimation is linearly predicted by their own BMI, but with a slope less than unity (see Fig. 3A): low BMI controls over-estimate body size, mid-range BMI controls' estimates are the most accurate and high BMI controls under-estimate. This pattern of responses is entirely consistent with a normal feature of magnitude estimation, i.e., contraction bias (Poulton, 1989). Contraction bias assumes that a body size judgement is made by comparing a body with an internal standard or reference based on an average of all the bodies that a person has ever seen. This judgement is most accurate when comparing a body similar in size to the internal reference body, and increasingly less accurate as the two diverge. In these latter cases, when there is an increasing difference between the reference and the body to be estimated, the observer tends to select a response closer to the reference value than it should be, hence the term contraction bias (i.e., sizes much larger than the reference are underestimated and smaller sizes than the reference are overestimated).

This contraction bias explanation is consistent with results from other studies. For example, Tovée et al. (2003) used a large

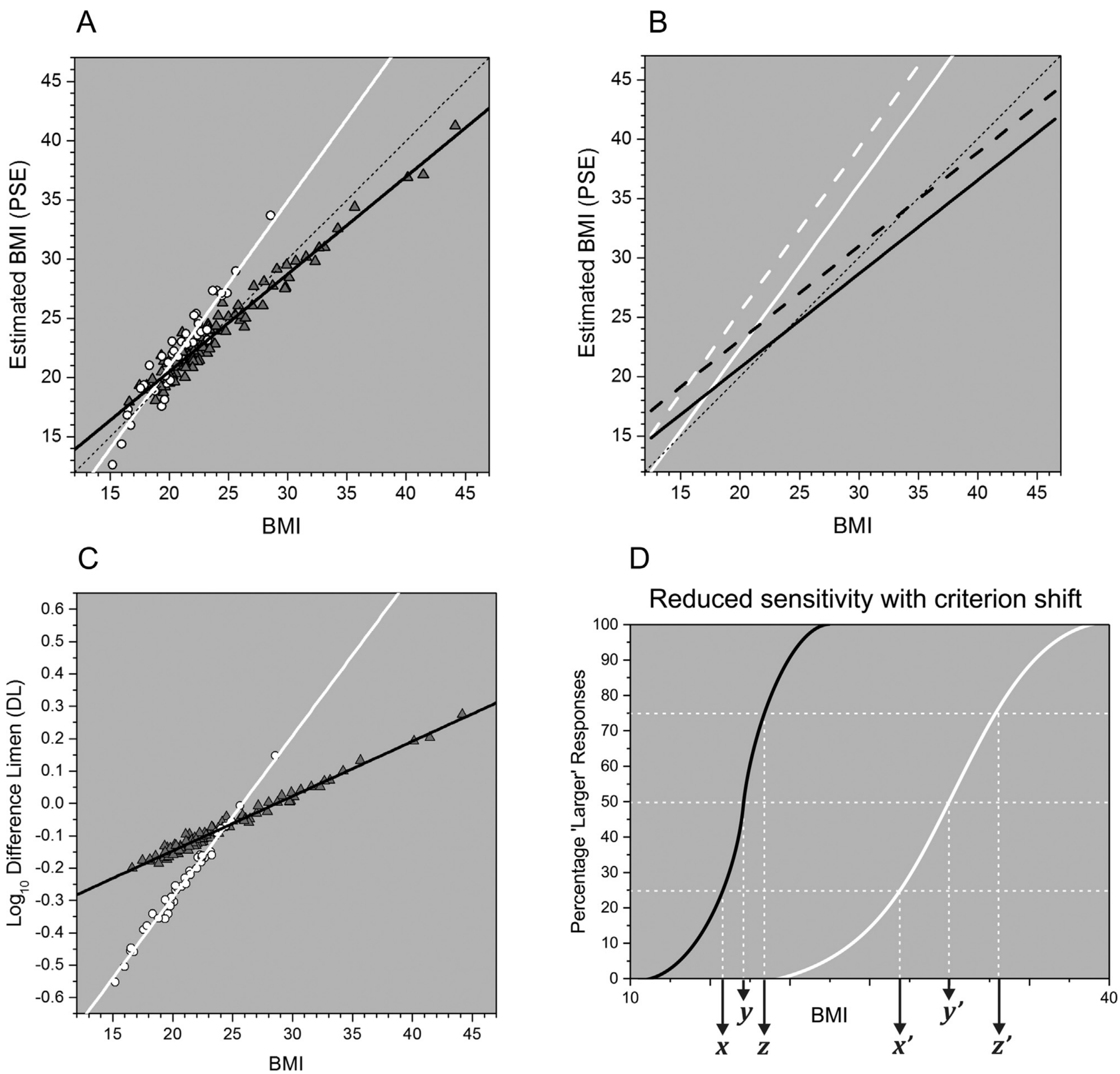

Fig. 3. (A) The relationship between participants' BMI (*x*-axis) and their subjective estimate of body size (PSE) with the effects of PSYCH statistically controlled. (B) The relationship between participants' BMI (*x*-axis) and fitted values of estimated body size (PSE) computed from the mixed model at ±1 *SD* of the mean PSYCH value for each group. (C) The relationship between participants' BMI (*x*-axis) and their sensitivity at estimating body size ($\log_{10}$ DL) with the effects of PSYCH statistically controlled. (D) A sketch plot to illustrate the relationship between the psychometric function for body size estimation and the calculation of PSE (i.e., the value of BMI at *y* and *y*′ when percentage 'larger' responses = 50%) and DL (i.e., the difference in BMI between *z* & *x* and *z*′ & *x*′. These points correspond to values of BMI when percentage 'larger' responses equal 75% and 25%, respectively). Two situations are illustrated: accurate and sensitive performance (black) versus over-estimating and insensitive performance (white).

sample of both eating disordered and control participants and found that as the participants' own BMI declines, their overestimation increases, with highest overestimation in the very low BMI individuals. Additionally contraction bias can also explain the fact that previous studies have consistently shown that obese people under-estimate their size relative to normal BMI people (Kuchler & Variyam, 2003; Kuskowska-Wolk & Rössner, 1989; Maximova et al., 2008; Robinson & Kirkham, 2013; Truesdale & Stevens, 2008; Wetmore & Modkdad, 2012). Critically, given that contraction bias is a normal attribute of our perceptual systems, these studies also suggest that there is a substantial perceptual component to body size estimation that will be dependent on an individual's own BMI and not on their psychological state.

Although contraction bias describes the gradient of the response between the accuracy of the estimation against the BMI of the body being judged by the controls, the intercept for this relationship is also influenced by body shape concerns (i.e., the function moves up or down the *y*-axis depending on the level of their psychological concerns, illustrated in Fig. 3B). This shows that for a body of a given BMI, the degree of size over- or under-estimation will also be modulated by the psychological state of the observer, even in the control participants.

The difference limen (DL) for the control participants rises as the participants' own BMIs rise (i.e., the participants' sensitivity to changing body size declines as their own BMI rises). This can be explained by another well-established perceptual effect, Weber's law. This states that the just noticeable difference (JND) between two stimuli will be a constant proportion of their magnitude, leading to a constant Weber fraction over the stimulus range (i.e., $\Delta I/I = K$, where I = stimulus magnitude and K = constant). This means that, for bodies, it is easier to notice, for example, a one BMI unit difference between two low BMI bodies than between two high BMI bodies. Over the full range of BMI, discriminating between higher BMI bodies requires progressively larger differences in BMI between stimuli, which in turn leads to progressively increasing DL values. Indeed, the data for controls in Fig. 3C show an excellent fit to Weber's Law because the Weber fractions at, e.g., BMI 20 and 40 are 0.036 and 0.038 respectively, which fall within 5% of each other.

In this study, women with ANSD showed a qualitatively different pattern of results compared to the controls, and these differences are statistically robust. For women with ANSD, the lowest BMI individuals are actually the most accurate in their body size estimation and they are also very sensitive to changes in body size (i.e., they show a low DL value) in low BMI bodies. This sensitivity is considerably greater than that seen for controls. However, as the ANSD individuals' BMI increases, they start to systematically over-estimate their body size (as indexed by PSE) and the magnitude of this over-estimation scales linearly with their BMI. This is reflected in the sharp increase in the DL values, indicating a rapid reduction in sensitivity to changes in body size as the BMI of the bodies' increases. Moreover, the gradient of this relationship for DL in women with ANSD far exceeds the prediction from Weber's law. Overall, therefore, the pattern of over- and under-estimation of body size is quite different to that described in the control participants, is the opposite of the pattern of responses predicted by contraction bias, and is more consistent with the prediction in Fig. 1C.

In Fig. 1C, we had originally hypothesised that the low BMI women with anorexia would have relatively low body size concerns and that the recovering women with anorexia would show an increase in concerns as their BMI rose. What we found was that women with ANSD did have greater psychological concerns, on average, than controls (see Table 2). However, the influence of psychological concerns on the relationship between personal BMI and body size estimation was the same for both groups (see the difference between continuous and dotted regression lines in Fig. 3B) – i.e., increasing psychological concerns were linked to higher body size estimations across the entire sample, changing the intercepts, but not the slopes, by the same amount for both groups. This means that changing psychological concerns cannot be directly responsible for the perceptual differences in the two groups that we observe, i.e., the different slopes for PSE and DL in Fig. 3A and C. Instead, we suggest that the key to explaining our findings lies in the different ways that women with ANSD *interpret* changes in body size and psychological concern, compared to controls. In what follows, we use signal detection theory, to account for the results in women with ANSD, based on the reduction in their sensitivity to changes in body size as the BMI of the bodies being judged increases.

Consider the paradigm being used. Each participant has to say whether a body being shown is fatter or thinner than themselves. As the BMI of ANSD participants increases, they become less able to distinguish small differences between the BMI of the stimuli and the body size they believe they have because they are less sensitive (i.e., increasing DL) to differences in body size (see Fig. 3C). This means that in order for a low BMI and a higher BMI woman with anorexia to have the same confidence in expressing a judgement about their respective body sizes, the participant who has a higher personal BMI, will only response 'larger than me' to stimuli that are, proportionately, considerably larger than they are, as compared to the participant who has a lower personal BMI. Psychophysically, this is reflected in a so-called criterion shift: i.e., not only does the slope of the psychometric function become shallower for the participant with a higher personal BMI (i.e., reduced sensitivity), but the curve itself is also shifted to the right (see Fig. 3D). Thus, we propose that because of their reduced sensitivity to changes in body size, the higher BMI ANSD participants shift their response criterion in order to remain confident that their responses are correct, which in turn causes an increase in PSE and consequent over-estimation of body size. We suggest that an insistence to maintain the same confidence in the decisions made by women with ANSD is consistent with their documented aversion to making errors in judgements (Kaye, Fudge, & Paulus, 2009; Wagner et al., 2007). We ran a post hoc correlation analysis which supports this interpretation, because the level of psychological concern in women with ANSD was positively correlated with body size estimates (i.e., PSE; $r = .30$, $p = .05$) but independent of sensitivity to body size change (i.e., DL; $r = .17$, $p = .29$). When we partialled out the influence of sensitivity (DL), the correlation between psychological concerns and body size estimation was rendered non-significant ($r = .25$, $p = .11$). This therefore suggests that sensitivity to change in body size plays a critical role in modulating the relationship between psychological concern and body size estimation in women with anorexia.

Gardner and Moncrieff (1988) used signal detection theory to analyse their data from a 2AFC task in which participants had to judge whether images of themselves were normal or distorted. While they found no difference in task sensitivity (indexed by d-prime) between women with AN and controls, nevertheless, the women with AN showed a more lax response criterion. Gardner and Moncrieff (1988) suggested that this may make women with AN more likely than controls to report an image of themselves as distorted. If we assume an average height for their sample of 1.6 m, then the average BMI of the women with AN and controls in the Gardner and Moncrieff study were ~17.5 and ~22 respectively. At these BMI levels, we do see marked differences in task sensitivity (indexed by DL) between women with ANSD and controls in the current study. We suggest two reasons for the differences between studies. The first is that Gardner and Moncrieff (1988) used the video distortion technique (VDT) to produce their body stimuli. As illustrated in Fig. 2, there are systematic differences in the body shapes produced by the VDT compared to our CGI method which might induce different patterns of responses in women with ANSD and controls. Secondly, it is possible that the use of a distortion question (i.e., normal versus distorted) may have invoked a different response pattern from the women with AN than the thinner or fatter question we used and which is potentially a more psychologically and emotionally charged judgement for them to make. Our results suggest that women with ANSD are extremely sensitive to shape change in low BMI bodies and so they may be better placed than controls to detect visual changes in the VDT images which do not usually accompany weight loss/gain. Further research is needed to clarify the nature and implications of these methodological differences.

While the account we have given of our data uses ideas from signal detection theory, it does leave open the question of what mechanism might cause the dramatic differences in task sensitivity demonstrated by women with ANSD; clearly a specific focus for future research. One possibility is that the higher sensitivity (i.e., lower DL) to changes in body size in ANSD women who have low BMI, relative to controls, is due to an expertise effect (i.e., the development of expertise in low BMI body discrimination). Women with AN spend a great deal of time looking at low BMI bodies including their own, but also online as part of their obsession with the thin ideal (Norris, Boydell, Pinhas, & Katzman, 2006; Ransom, La Guardia, Woody, & Boyd, 2010). This could explain why our participants were more sensitive to low BMI body change than the controls. Repeated evaluation and discriminations of low BMI bodies could allow the development of an expertise in discriminating between low BMI bodies. ANSD individuals' sensitivity to size change in higher BMI bodies showed a rapid decline, far faster than is seen in the control participants. Body shape changes in a non-linear fashion with increasing BMI (Wells, Treleaven, & Cole, 2007), so the pattern of shape change with weight increase is different in low BMI bodies as compared to heavier BMI bodies. Arguably, therefore, the expertise developed by women with ANSD might be specific to low BMI bodies and may not generalise to discriminating between higher BMI bodies.

Although we have emphasised the role of perceptual factors in our explanation, we acknowledge that a range of psychological, cultural and socio-economic factors influence our judgement of bodies. A number of studies have suggested that we make judgements about complex stimuli such as faces and bodies by reference to a template based on the average of all that class of stimuli that they have seen (e.g., Leopold, O'Toole, Vetter, & Blanz, 2001; Winkler & Rhodes, 2005). This average can be selectively manipulated by showing a sequence of thin or fat bodies to shift an observer's perception of what constitutes a normal body (Winkler & Rhodes, 2005). However, this "visual diet" is not the only factor in preferred body size. For example, showing larger bodies in a positive light can increase the preference for larger bodies (Boothroyd, Tovée, & Pollet, 2012). An example of this "visual valency" is the change in body preferences as people move between cultures. People living in rural KwaZulu Natal in South Africa prefer a much larger BMI (Tovée, Swami, Furnham, & Mangalparsad, 2006), but people from KwaZulu Natal moving to the UK shift their preferences towards a lower BMI. The average BMI of people in both regions is not significantly different, but in KwaZulu Natal a heavier body is associated with health and higher socioeconomic status whereas in the UK the opposite is the case. Thus, it is the value placed a particular body size by a culture that seems to predict preferred body size. So multiple factors influence body preferences.

Our results have important implications for treatment of people at both ends of the weight spectrum. Women with ANSD are very accurate in their body size judgements when they have a low BMI (BMI < 17.5) and tend to actually slightly under-estimate their body size. This suggests that body size over-estimation as a maintenance factor for low BMI women with anorexia has a comparatively weak effect. However, as they are very sensitive to changes in the size and shape of a low BMI body, they are also able to detect any increase in their weight. This may stimulate a renewal of weight reduction behaviours. In this case it is not an inaccurate perception of their body that is the potential problem, but instead their ability to accurately detect weight increase.

However, as their BMI rises, women with ANSD rapidly develop an over-estimation of their body size and a rapid decrease in the sensitivity with which they can detect changes in body size. These changes occur significantly faster as participant BMI increases in women with ANSD as compared to controls of a corresponding BMI (see Fig. 3A and B). This has important implications for potential relapse in recovering patients. They will see themselves as larger than they actually are and a large proportion of this over-estimation will be based on perceptual factors not easily treated through talking therapies such as cognitive behavioural therapy (CBT). Given the core nature of body size concerns for AN (Cash & Deagle, 1997; Fairburn et al., 2003), this represents a potentially important factor in any subsequent relapse and may contribute to the relatively high relapse rate (Channon & DeSilva, 1985; Slade & Russell, 1973). However, this is not to say that CBT cannot play a role in reducing body size over-estimation. For a given BMI, our results suggest that the degree of over-estimation by women with ANSD is modulated by their body size and shape concerns. So talking therapies such as CBT, can potentially reduce the over-estimation of body size by targeting these concerns. However, to improve perceptual judgements a perceptual training programme may also be needed to try and recalibrate their judgements.

The results also have significant implications for the treatment of obesity. A number of studies have suggested that levels of obesity are increasing in the general population (Ogden et al., 2006; Swinburn et al., 2011). At the same time, it has been reported that people who are overweight have difficulty in detecting that their weight is increasing (Truesdale & Stevens, 2008; Wetmore & Modkdad, 2012). This has been explained by an adaptation effect, suggesting that the general trend in the population to be heavier has redefined what we judge to be overweight (Robinson & Kirkham, 2013). However, our results suggest two other factors could also play a role. Firstly, contraction bias produces a systematic under-estimation of our body size as we gain weight. Secondly, Weber's law predicts that we will be systematically less able to detect weight increase (as indexed by the JND) as our BMI rises. Both of these factors could act to make it more difficult for overweight people to detect weight increase, and so reduce the probability of a person taking weight control measures (Wardle, Haase, & Steptoe, 2006; Wetmore & Modkdad, 2012). This could potentially be treated by a training programme which would improve discrimination of heavier bodies (the development of the "expertise effect" which reduce the JND for higher BMI bodies).

This study uses CGI 3D modelling to produce photorealistic bodies with a biometrically accurate simulation of weight change. These techniques are in increasing use as the modelling software becomes more user friendly to non-computer scientists and at the same time produces more realistic results (e.g., Evans, Toveé, Boothroyd, & Drewett, 2013; Frederick, Hadji-Michael, Furnham, & Swami, 2010; Glauert, Rhodes, Byrne, Fink, & Grammer, 2009; Tovée, Edmonds, & Vuong, 2012). This allows the use of sets of bodies which hold constant such features as their skin texture, proportions and facial features. However, we would underline the importance of biometric validation of these images as the software used to generate these images does not produce simple linear changes in body size and without careful calibration of the resultant bodies, they may not be biometrically accurate and therefore may introduce a whole new set of artefacts into body research.

In conclusion, our results suggest that body size over-estimation is not only much more variable than might have been appreciated previously, given the strong dependence on individual BMI, but it also shows striking differences between women with ANSD and controls. The accuracy of control participants can be explained by the combined effects of two perceptual functions, contraction bias and Weber's law, with a modulating effect of psychological concerns about body size. By comparison, as their BMI increases, the accuracy of estimation by women with ANSD seems to be predicted primarily by a rapid criterion shift which is to compensate for a rapid decline in sensitivity to body size change.

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