Body Size Estimation in Eating and Weight Disorders

Dissertation

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Ich erkläre, dass ich die zur Promotion eingereichte Arbeit mit dem Titel "Body Size Estimation in Eating and Weight Disorders" selbständig verfasst, nur die angegebenen Quellen und Hilfsmittel benutzt und wörtlich oder inhaltlich übernommene Stellen als solche gekennzeichnet habe. Ich versichere an Eides statt, dass diese Angaben wahr sind und dass ich nichts verschwiegen habe. Mir ist bekannt, dass die falsche Abgabe einer Versicherung an Eides statt mit Freiheitsstrafe bis zu drei Jahren oder mit Geldstrafe bestraft wird.

I hereby declare that I have produced the work entitled "Body Size Estimation in Eating and Weight Disorders", submitted for the award of a doctorate, on my own (without external help), have used only the sources and aids indicated and have marked passages included from other works, whether verbatim or in content, as such. I swear upon oath that these statements are true and that I have not concealed anything. I am aware that making a false declaration under oath is punishable by a term of imprisonment of up to three years or by a fine.

Tübingen, 2. August 2017

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Synopsis

Abstract

Body image disturbance is a core feature of eating disorders and is also mentioned as being relevant for the development and maintenance of obesity. Despite its important role in conceptualizations of eating and weight disorders and their treatment, there is still a remarkable lack of knowledge about the specific characteristics of body image disturbance. The present thesis uses an updated theoretical framework and a multi-method account involving innovative methods to disentangle and evaluate the role of different body representations for body image disturbance. A transdiagnostic perspective is adopted, with a focus on anorexia nervosa.

The thesis encompasses four sub-projects. Study A provides a systematic review and meta-analysis of body size estimation accuracy in anorexia nervosa and bulimia nervosa. Unlike previous reviews, it uses an updated theoretical framework of body size estimation that accounts for method-specific differences in the assessed representations. Study B applies the theoretical framework to multi-method data obtained from obese children in weight loss treatment, compares their performance to that of normal-weight children and provides an overall analysis of associations between different measures. Study C uses a technically innovative body size estimation paradigm along with other measures to evaluate different components of body representation in women with anorexia nervosa and healthy controls and associations between different measures. Study D uses optimized figure rating scales as a quick and easy means of evaluating body image disturbance in anorexia nervosa and additionally examines effects of scale range and associations with other measures of body representation. Wrapping up the different studies, the project yielded clear evidence of a cognitive-affective disturbance characterizing body image disturbance, but no hint of a visual perceptual distortion in the sense of disturbed awareness in eating and weight disorders.

On a conceptual level, the project supports the perspective of body representation as a conglomerate of different representations that are mutually interacting. In this perspective, it is overly simplistic to speak of disturbed body perception or general cognitive-affective disturbance. Rather, body image disturbance should be understood as a phenomenon arising from disturbances in single representations or their integration.

Clinically, the present projects demostrates that although inaccurate body size estimation frequently occurs in eating and weight disorders, it is not due to a general lack of awareness regarding the own size. The present results also emphasize differences between body image disturbance in obesity and anorexia nervosa. While obese individuals mainly suffer from high body dissatisfaction, body image disturbance in anorexia nervosa seems to be characterized by incoherent representations of the body. Further research is needed to clarify to what extent this is due to disturbances in isolated representations or to integration processes.

List of Abbreviations

AN	anorexia nervosa
BED	binge eating disorder
BID	body image disturbance
BMI	body mass index (kg/m^2)
BN	bulimia nervosa
FRS	figure rating scale
OSFED	other specified feeding or eating disorder
VR	virtual reality

> Evaluation of the disturbance in body image is of importance not only as a diagnostic criterion, but also in appraising treatment progress. Anorexic patients may gain weight for many reasons or may seem to progress well in psychotherapy. Without a corrective change in the body image, however, the improvement is apt to be only a temporary remission.
>
> *(Hilde Bruch, 1962)*

Theoretical background

Body image disturbance (BID) is a core feature of eating disorders and is also mentioned as being relevant for the development and maintenance of obesity. Although everyone working in the field of eating and weight disorders seems to have a precise concept of BID, there is still a remarkable lack of knowledge about its specific characteristics and underlying mechanisms. For example, it is still unknown whether or not BID encompasses a perceptual disturbance in a narrow sense and generally, evidence on the extent and dynamics of BID is scarce. The question of the nature of BID has direct implications for the advancement of treatment approaches in the field of eating and weight disorders. The present thesis aims to contribute to the ongoing debate by developing an up-to-date framework for the study of body image disturbance, and by disentangling and evaluating the role of different BID components in eating and weight disorders with a focus on anorexia nervosa.

Eating and weight disorders

Diagnostic manuals currently distinguish between four categories of eating disorders: anorexia nervosa (AN), bulimia nervosa (BN), binge eating disorder (BED) and other specified feeding or eating disorder (OSFED). AN and BN are characterized by BID that goes hand in hand with abnormal eating behavior characterized by restrictive food intake and/or episodes of binge eating and compensatory measures (American Psychiatric Association, 2013; *ICD-10-GM*, 2016). BED is characterized by recurrent binge eating episodes without compensatory behavior. People with OSFED present with significant symptoms of eating disorders, but do not meet the full criteria of AN, BN or BED. The point prevalence of AN is estimated at 0.3%, of BN at about 1% and of OSFED and BED at about 2.4% in young women (Smink, Van Hoeken, & Hoek, 2012). Although eating disorders are relatively rare at population level, they still impose a considerable burden.

Psychological and physical comorbidities of eating disorders are high, and treatment is often difficult. Longitudinal studies show that less than half of patients with AN and BN achieve full remission (Zipfel, Löwe, Reas, Deter, & Herzog, 2000; Steinhausen, 2002; Steinhausen & Weber, 2009). A meta-analysis assigned elevated mortality rates to patients with eating disorders and concluded that AN has the highest mortality rate among all psychiatric disorders (Arcelus, Mitchell, Wales, & Nielsen, 2015). Recent estimates have suggested that in the European Union, AN and BN alone cause direct and indirect costs of more than EUR 800 million per annum (Olesen, Gustavsson, Svensson, Wittchen, & Jönsson, 2012). The estimated costs of all eating disorders, that is including BED and OSFED, plus additional indirect costs, are much higher. Overall, disease costs are estimated to be higher than those of anxiety and depression (Schmidt et al., 2016).

Obesity is not a defined eating disorder, but characterized only by a body mass index (BMI; kg/m^2) of at least 30. It is still a matter of debate as to whether obesity should be considered a disease (*Interdisziplinäre Leitlinie der Qualität S3 zur „Prävention und Therapie der Adipositas" Version 2.0*, 2014). Obesity is a worldwide phenomenon with increasing prevalence rates. In 2014, it affected approximately 11% of men and 15% of women worldwide, with even higher rates in Europe and North America (NCD Risk Factor Collaboration, 2016). Notably, prevalence is also rising in children and adolescents, and childhood obesity often transfers into adulthood (Ogden et al., 2016; Singh, Mulder, Twisk, Van Mechelen, & Chinapaw, 2008). Obesity is a risk factor for the development of physical morbidity and even for mortality (Flegal, Kit, Orpana, & Graubard, 2013; "Expert panel report: Guidelines (2013) for the management of overweight and obesity in adults," 2014), but also poses risks for psychological well-being and increases the risk of psychological disorders such as depression and generalized anxiety disorder (Wardle & Cooke, 2005; Luppino et al., 2010; Kasen, Cohen, Chen, & Must, 2008). The primary cause of obesity, namely excess energy intake compared with energy consumption, seems almost trivial. However, the etiology of obesity is extremely complex.

Although metabolism has been recognized as an important factor in weight management, current frameworks emphasize the role of socio-cultural and psychological factors (Gearhardt et al., 2012; Bénard et al., 2017; Hendrikse et al., 2015; Schag, Schönleber, Teufel, Zipfel, & Giel, 2013; Leehr et al., 2015). In this perspective, energy intake and energy consumption are determined by rest mode consumption, eating behavior and physical activity which, in turn, are determined by genetic, socio-cultural and psychological factors (Herpertz & Senf, 2003). On an individual level, transdiagnostic accounts of eating and weight disorders acknowledge that cognitive-affective aspects are the most relevant mechanisms for the development and maintenance of eating and weight disorders (McClelland et al., 2016; Fairburn, Cooper, & Shafran, 2003; Duarte, Ferreira, & Pinto-Gouveia, 2016; Fox & Power, 2009). Consequently, the S3 Guideline for the treatment of eating disorders not only lists changes in eating behavior, but also the treatment of underlying psychological symptoms as therapeutic aims (Herpertz, Herpertz-Dahlmann, Fichter, Tuschen-Caffier, & Zeeck, 2011).

In clinical practice, standard interventions currently accord top priority to the normalization of eating behavior and eventually weight using self-monitoring, psychoeducation, and the introduction of regular balanced meals (Herpertz & Senf, 2003; Friederich, Herzog, Wild, Zipfel, & Schauenburg, 2014; Herpertz et al., 2011; Becker, Zipfel, & Teufel, 2015; Legenbauer & Vocks, 2006). To address the underlying problems, these measures are complemented by disorder and therapy specific techniques such as cognitive restructuring, skills training for emotion regulation, the analysis and addressing of interpersonal problems or even physical activity (Herpertz & Senf, 2003; Friederich et al., 2014). Specific interventions targeting body image have been developed, but they are playing a subordinate role in standard treatments to date (Legenbauer & Vocks, 2006; Friederich et al., 2014; Farrell, Shafran, & Lee, 2006; Herpertz et al., 2011). This may also be because distinctive features of BID are still unknown.

Body image disturbance

BID refers to an overvaluation of one's appearance, possibly combined with difficulties in correctly gauging one's size and with pronounced body avoidance or checking behavior. It is a transdiagnostic feature of AN and BN and assumed to be the core psychopathology of eating and weight disorders (Fairburn et al., 2003). Self-report procedures in the form of semi-structured interviews or questionnaires have been established for the assessment of BID, but experimental setups using specific devices are also commonly used (Steinfeld, Bauer, Waldorf, Hartmann, & Vocks, 2017; Farrell, Lee, & Shafran, 2005; Gaudio, Brooks, & Riva, 2014). The different measures of BID are assumed to capture different aspects of BID.

The currently most widely used framework of BID assumes a subdivision of body representation into cognitive-affective, behavioral and perceptual components (Bruch, 1962; Cash & Deagle, 1997; Legenbauer, Thiemann, & Vocks, 2014; Steinfeld et al., 2017). The cognitive-affective component of BID refers to the evaluation of one's own appearance and its significance for the self-concept. The behavioral component refers to body-related avoidance or control behavior, such as body-checking or comparisons with other people. The perceptual component is typically understood to be a distorted perception of one's own body in the sense of an overestimation. While there is convergent evidence on the contribution of cognitive-affective processes to body image disturbance (Duarte et al., 2016; Fox & Power, 2009; Legenbauer et al., 2011; Schwartz & Brownell, 2004), the nature and extent of the perceptual component, and especially the issue of whether it might underlie the cognitive-affective and behavioral components, is still unclear. This lack of knowledge has repeatedly been identified as a major hurdle to the development of efficient treatments (Farrell et al., 2006; Alleva, Sheeran, Webb, Martijn, & Miles, 2015; Pennesi & Wade, 2016).

Body Size Estimation

Many studies investigating BID have focused on visual perception of body size using body size estimation (BSE) tasks. BSE tasks were developed in the 1960s and 1970s in pursuit of an objective measure to determine the extent of body image disturbance (Slade & Russell, 1973). At least two types of method can be distinguished. In metric methods, participants use spatial analogues like calipers, rods, or distances between points to express their estimates of specified body dimensions, for example waist width or stomach depth. In depictive methods, participants are presented with gradually distorted images or videos of themselves, and select the image that corresponds best to their actual body. A conceptually related method is that of Figure Rating Scales (FRS). FRS are a paper-pencil version of depictive methods in which participants pick the body that best matches their own or their ideal body from a list of figural drawings varying in weight (Gardner & Brown, 2010). Distortion, as assessed through these measures, has also sporadically been used as indicator for BID severity (Keizer, Van Elburg, Helms, & Dijkerman, 2016; Sala et al., 2012).

So far, evidence on BSE in eating and weight disorders is inconsistent and partly inconclusive. Many, but not all studies using metric and depictive methods observed that persons with AN and BN overestimate their body size (cf. Fig 1). Therefore, BSE accuracy has sporadically been used as an outcome of interventions aiming to improve BID (e.g. Keizer et al., 2016). Similarly, some of the studies that used figure rating scales observed that persons with acute AN or BN overestimate their size (Moscone, Amorim, Le Scanff, & Leconte, 2017; Sala et al., 2012; Striegel-Moore et al., 2004) while other studies suggested that persons with eating disorders estimate their size quite accurately. Interestingly, some studies suggested the opposite pattern in overweight individuals, that is underestimation of size (K. K. Cornelissen, Gledhill, Cornelissen, & Tovée, 2016; Ratcliff, Eshleman, Reiter-Purtill, & Zeller, 2012). However, Gardner (2014) emphasized that, depending on the exact method and instructions used, this effect could not be replicated in other studies.

How to interpret findings from BSE tasks, and how to evaluate the construct validity and ecological validity of BSE are matters of ongoing debate. Some authors argue that depictive methods might be superior to metric methods in terms of ecological validity, as they mimic the real-life situation of looking at oneself in a mirror, whereas metric methods do not (Farrell et al., 2005; Gardner & Brown, 2014). However, there are also concerns about the ecological validity of depictive methods because the non-biometric weight morphing algorithms used in most studies might have biased results (K. K. Cornelissen, Bester, Cairns, Tovée, & Cornelissen, 2015). Notwithstanding, several explanations have been suggested to account for body size overestimation in AN and BN and for underestimation in overweight and obesity.

A very common interpretation of BSE in eating and weight disorders is that the misestimation reflects fundamental perceptual deficits which prevent patients from accurately recognizing their weight. This inaccurate weight perception is considered a central etiologic and maintaining factor in both weight regulation (Gardner & Brown, 2014; Preston & Ehrsson, 2014) and the lack of weight gain counteraction (Ratcliff et al., 2012; Lu et al., 2015). More recent variations of this idea hypothesize that bottom-up distorted representations might be insufficiently corrected by top-down cognitions (Longo, 2015), that memories of one's own appearance might not be sufficiently updated by sensory inputs (Riva, 2012), that selective attention to unfavorable body parts might cause a distorted perception (Tuschen-Caffier et al., 2015; P. L. Cornelissen, Johns, & Tovée, 2013), or that multi-sensory integration of nonvisual sensory representation fails (Gaudio et al., 2014). Other authors, however, have argued that the misestimation might not reflect any perceptual disturbance in the narrow sense, but rather cognitive-affective aspects of body image disturbance or biases induced through task or setting characteristics.

Opponents of this perceptual deficit hypothesis argue that, in the light of numerous non-findings and relatively small effect sizes, it is actually still uncertain whether patients with eating disorders really do overestimate their size (Cash & Deagle, 1997; Gardner, 2014; Hsu & Sobkiewicz, 1991). As illustrated in , many studies have not found

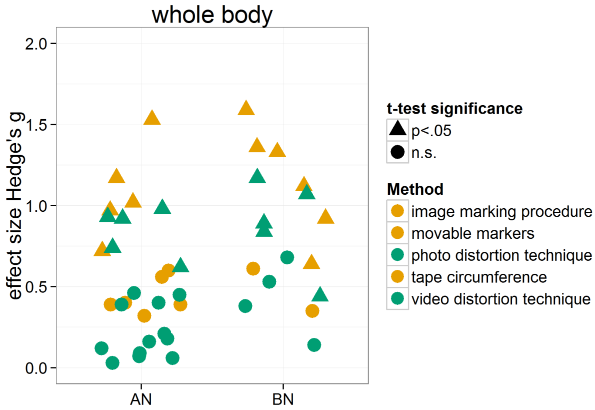

Figure 1: Illustration of effect sizes from patien versus control comparisons in BSE tasks as analyzed in study A. Green indicates depictive methods, orange indicates metric methods.

any overestimation at all. Several psychophysics studies have questioned whether overestimation, if found, is due to perceptual deficits (Smeets, 1997; Gardner & Bokenkamp, 1996). Instead, it has been suggested that propositional representations such as verbal representations of the body might be distorted so that thinner bodies are still labeled as "fat" (Smeets, 1997) or fatter bodies as "normal" (Oldham & Robinson, 2015), or that body size estimation tasks might be sensitive to demand effects in the sense that participants could adapt their responses to confirm the believed hypothesis (Smeets et al., 2009). Lastly, it was recently hypothesized that misestimation could be a secondary effect of non-average body weight because comparisons of one's own weight with a measure might be biased towards the average body weight (K. K. Cornelissen et al., 2015). As previous studies have mostly used single methods only, a comprehensive evaluation of these arguments has not been possible to date.

Aims of the present work

The present project aims to achieve a better understanding of BID in eating and weight disorders, specifically in AN. To this end, body size estimation findings were reviewed and an up-to-date theoretical framework was developed for their interpretation. Further, BSE paradigms were advanced together with cooperation partners with a view to improving ecological validity, but also data quality and facilitating an interpretation of BSE performance. To this end, well-controlled assessments, a sophisticated model of human body shape and, for one study, even individual body scans and virtual reality were used. illustrates this process.

Within the project, a series of studies was conducted in individuals with eating and weight disorders across the weight range. All studies used multi-method approaches

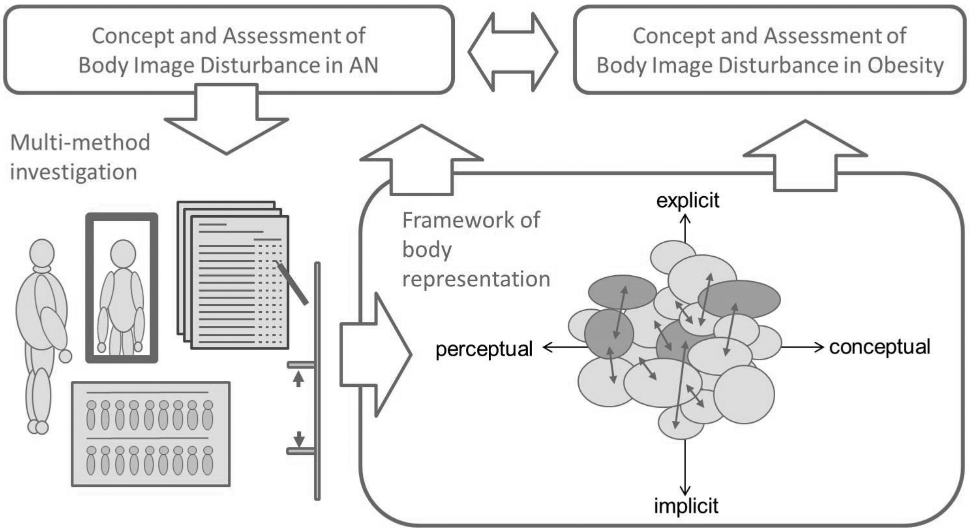

Figure 2: Illustration of the project concept.

involving perceptual and cognitive-affective body representations. Thus, a more comprehensive picture of distorted and non-distorted body size representation, including associations between different measures of body representation, was obtained. Three out of four sub-projects involved individuals with AN, and one sub-project was on obese individuals, so that comparisons between the disorders are possible and tentative conclusions about the etiology of BID in AN can be drawn. The main focuses of the sub-projects were as follows:

A) BSE meta-analysis: Analyze current empirical evidence on BSE in eating disorders and develop a theoretical framework that incorporates recent advances in fundamental research

B) BID in obese children: Apply the theoretical framework to a multi-method data set assessed in obese children and adolescents as well as in a normal weight control group and evaluate group differences and associations between different components of body representation in the same individuals

C) BSE in AN using VR: Develop advanced depictive body size estimation tasks that use psychophysics to disentangle different components of body image and have maximized ecological validity through use of a statistical body model, individual body scans and virtual reality presentation of bodies. Apply the tasks along with questionnaires to individuals with AN and healthy controls to evaluate different components of body representation

D) FRS in AN: Optimize figure rating tasks so that it is also possible to investigate body weight perception accuracy in a valid way. Assess individuals with AN and controls using a wide weight spectrum with the FRS and established questionnaires to investigate group differences, effects of scale range, and associations between the measures

Project overview and summary of results

All sub-projects of this thesis project investigated body size estimation in individuals with an eating or weight disorder, but varied as regards exact measures and targeted individuals. Also, all empirical studies used multi-method accounts to facilitate the interpretation of possible group differences and to advance the construct validity of body image representation. Given that body image disturbance is assumed to be a transdiagnostic core pathology of eating and weight disorders, the advantage of this approach is that it enables a broad picture to be painted and thereby maximizes the validation of our new theoretical framework. To also test the feasibility of our approach for a single diagnosis, three of the four studies encompassed data from individuals with AN, thereby enabling a more detailed analysis of body image disturbance in AN. Table 1 provides an overview of the four studies, whereas a more detailed description of what the respective studies added to the previous literature is provided below.

Study A) BSE meta-analysis

Full title: Depictive and Metric Body Size Estimation in Anorexia Nervosa and Bulimia Nervosa: A Systematic Review and Meta-Analysis

Study A is a systematic review and meta-analysis of studies that compared body size estimation accuracy between patients with anorexia nervosa and bulimia nervosa. We were not the first to review body size estimation in AN and BN, but previous reviews either focused only on children and adolescents (Legenbauer et al., 2014) or were relatively old, and all had concluded that evidence is inconclusive with regard to mechanism-oriented models of body image disturbance (Smeets, 1997; Farrell et al., 2005; Gardner & Brown, 2014). The last meta-analysis of BSE tasks was from Cash and Deagle (1997), and had a very broad focus with respect to the measures included. None of the previous reviews had provided a comprehensive theoretical framework for the interpretation of body size estimation, despite the profound evolution in theoretical frameworks of body representation (Schwoebel & Coslett, 2005; de Vignemont, 2010; Berlucchi & Aglioti, 2010; Dijkerman & de Haan, 2007; Longo, Azañón, & Haggard, 2010).

In this study, we adapted a novel theoretical framework proposed by Longo et al.

(2010) and Longo (2016) to match body size estimation tasks. We conducted a systematic review and meta-analysis of studies reporting group comparisons of controls versus individuals with either AN or BN, and analyzed whether the type of task or patient diagnosis moderates the effect size. Overall, we found that patients with AN and BN have been reported to overestimate their size, and that metric methods produce greater overestimation than depictive methods. Moreover, we observed that even healthy controls tend to overestimate their size in metric methods, while they are generally accurate in depictive methods. We concluded that the two task types likely address different body representations and that, in AN and BN, explicit representation of one's own size might be less affected than implicit size representation.

Study B) BID in obese children

Full title: Multimodal body representation of obese children and adolescents before and after weight-loss treatment in comparison to normal-weight children

Study B applies the theoretical framework to data obtained from obese children and adolescents and a normal weight control group, and investigates whether body image disturbance in obesity is mainly characterized by cognitive-affective components or also by misperception of one's own body. A multi-method account is selected that uses metric size estimation, tactile size estimation - which is supposed to result in even more implicit body representations - heartbeat perception accuracy as a measure of interoception and a body dissatisfaction questionnaire. We observed that obese children do not underestimate their size or have generally poor introspective abilities, but that they are very dissatisfied with their weight. Interestingly, while there were some correlations between size-associated measures and questionnaire data, heart beat perception accuracy was completely independent from the other measures.

Study C) BSE in AN using VR

Full title: Assessing body image in anorexia nervosa using biometric self-avatars in virtual reality: Attitudinal components rather than visual body size estimation are distorted

Study C exploits current technical capabilities in optimizing depictive BSE tasks and combines psychophysical methods and questionnaires to disentangle perceptual and attitudinal components of body image disturbance in AN. For this study, I worked together with collaborators and we generated individual biometric 3D avatars for each participant, based on individual laser scans of the body shape and a statistical body model. The avatars could be morphed in terms of weight and also allowed for the generation of weight- and shape-matched control avatars with another identity. Avatars were then presented on a life-size stereoscopic screen mimicking the situation of looking at oneself in a mirror to make the setup as ecologically valid as possible. Participants selected their estimated current and ideal body in three psychophysical tasks. Women with AN were proven to identify their veridical body weight accurately, or even to underestimate their weight. A control experiment with the weight- and shape-matched avatars with another identity showed that, in general, patients with AN were well able to memorize and identify bodies of their own weight and shape. By contrast, women with AN showed a clear preference for extremely thin bodies. Correlation analyses revealed that the discrepancy between estimated current and ideal body weight, but not perceptual distortion, was associated with interview coding of eating disorder pathology and questionnaire body dissatisfaction.

Study D) FRS in AN

Full title: Investigating body image disturbance in anorexia nervosa using novel biometric figure rating scales

For study D, I again worked with our collaborators to develop biometric FRS. A great advantage of these novel FRS was that, unlike previous FRS, the body mass index of the depicted figures was known in our scales. Hence, it was possible to derive parameters not only for body weight dissatisfaction, but also for perceptual distortion in the sense of accuracy in identifying one's weight on FRS. As in study C, it was observed that women with AN were accurate in the sense that they picked the body that corresponded best to their current weight, independent of the provided range, and patients with AN showed a preference for extremely thin bodies. Further, the results suggested that the FRS range provided may influence participants' choices, although mainly in controls where the scale range changed according to whether the participant's true body weight was above or below the scale midpoint.

	Study A: BSE meta-analysis	Study B: BID in obese children	Study C: BSE in AN using VR	Study D: FRS in AN
Sample	926 AN, 536 BN and 1920 controls (adults)	60 obese, 27 normal-weight controls (children)	24 AN, 24 healthy controls (adults)	24 AN, 104 controls (adults)
Design	Review and meta-analysis of studies in individuals with AN or BN reporting comparisons to controls in BSE	Multi-method analysis of various traditional body representation measures: metric body size estimation, tactile body size estimation, heart beat perception accuracy, questionnaire attitudes towards one's body. Obese children were followed up after a weight loss treatment.	Optimized BSE task with individual digital avatars that were weight-morphed based on a statistical body model and presented in virtual reality. Psychophysics allowed distinction between perceptual and attitudinal components of body representation	Optimized FRS with biometric avatars with known weight; allowed for distinction between perceptual and attitudinal components of body representation in a very sparse setup
Outcomes	Effect sizes from group comparisons between eating disordered and control group in BSE accuracy (BSE accuracy operationalized through Body Perception Indices, estimated/ actual size * 100)	BSE accuracy, Tactile size estimation accuracy, Heartbeat perception accuracy, Attitudes towards one's body	BSE accuracy (distortion) (2x), Sensitivity towards weight loss, Sensitivity towards weight gain, Desired weight change, Desired-vs-actual-discrepancy, Questionnaire body dissatisfaction and interview data on eating disorder symptoms	FRS BSE accuracy, FRS body weight dissatisfaction, Questionnaire body dissatisfaction and eating disorder symptoms
Independent variables	Eating disorder diagnosis (AN vs. BN), BSE method (depictive vs. metric)	Group (obese versus normal weight), Time (before/after weight loss; obese only)	Group	Group, BMI range of FRS
Statistical Analysis	Random-effects meta-regression with eating disorder diagnosis and BSE method as moderators	ANOVAs, Group-wise correlations between measures	ANOVAs, Group-wise correlations between outcomes and questionnaire/interview measures of eating disorder symptoms	U-Tests, Wilcoxon-Signed Rank-Tests, Group-wise correlations between measures

Main results	Overall effect suggesting that AN and BN patients overestimate their size, BN overestimate > AN > controls, Effect sizes in metric > depictive methods	Metric BSE accuracy: n.s. in group comparison and n.s. over weight-loss treatment	Depictive BSE accuracy: n.s. or AN underestimate > controls	FRS BSE accuracy: n.s. or AN more accurate than controls depending on scale
		Desired weight change (desired-estimated discrepancy): AN < controls, i.e. AN satisfied while controls desired a thinner body	FRS body dissatisfaction (desired-estimated discrepancy): AN < controls, i.e. AN satisfied while controls desired a thinner body BSE desired-actual discrepancy: AN < controls, i.e. AN desired a body close to their actual weight and controls desired a thinner one Sensitivity to weight gain or loss: n.s., all participants more willing to accept a thinner body as own than fatter one	
		Questionnaire body dissatisfaction: OBE dissatisfaction > controls, in one out of two scales significant improvement after weight loss	Questionnaire body dissatisfaction and eating disorder symptoms based on interview: AN dissatisfaction/symptoms > controls (different scales)	Questionnaire body dissatisfaction and eating disorder symptoms: AN dissatisfaction > controls (different scales)
		Tactile size estimation accuracy: OBE overestimate > controls, n.s. changes over weight loss therapy Heartbeat detection accuracy: n.s. in group comparison, significant improvement after weight loss therapy		
Associations between measures		Metric BSE accuracy with tactile size estimation accuracy, and questionnaire body dissatisfaction, Heartbeat perception accuracy non-correlated with other measures	BSE body dissatisfaction and desired-actual discrepancy, but not accuracy or sensitivity correlated with questionnaire body dissatisfaction and eating disorder symptoms	FRS body dissatisfaction but not FRS BSE accuracy correlated with questionnaire body dissatisfaction and eating disorder symptoms

Table 1: Overview of current status, design and main outcomes of the four sub-projects.

Discussion

Wrapping up the different studies, my dissertation project yielded clear evidence of a cognitive-affective disturbance characterizing BID in eating and weight disorders, but no hint of a visual perceptual distortion in the sense of disturbed awareness. The present project adds to previous studies drawing similar conclusions (Fernandez-Aranda, Dahme, & Meermann, 1999; Gardner, 2014; Smeets, 1997; Hsu & Sobkiewicz, 1991). Thanks to methodological advances, it not only provided convincing new data, but the reconceptualization of BSE also enabled a re-evaluation of previous studies and offered new insights into circumstances provoking inaccurate body size estimation.

Synthesis and interpretation of results

As outlined in the systematic review and meta-analysis (study A), there is accumulated evidence that, overall, persons with AN and BN have been observed to overestimate their size. However, upon closer examination as taken in studies C and D, it seems unlikely that this overestimation is due to general difficulties in visually estimating one's size. Both in the VR experiment and in the FRS assessment, participants with AN showed that they rationally know about their size and are also well capable of identifying their weight on images. Importantly, we also observed no general effect in the sense that women with eating disorders generally show a bias towards the average weight in BSE tasks (P. L. Cornelissen et al., 2013; K. K. Cornelissen et al., 2015). This was especially clear in experiment 2 of study C, where participants memorized and accurately estimated the size of another person matched to their body shape (and weight). Furthermore, in neither study C nor D was the degree of inaccuracy in estimation associated with eating disorder symptoms. Only for obese children were eating concerns and body dissatisfaction significantly associated with overestimation, but correlations were small. Hence, it can be concluded that although inaccurate body size estimation frequently occurs in eating and weight disorders, it is not due to a general lack of awareness regarding one's own size.

In contrast to the non-significant findings regarding awareness of people's own body size, there was consistent evidence across all studies supporting cognitive-affective body image disturbance. In study A, it was observed that the effect size patterns suggest that BSE involves conceptual representations such as attitudes. In study B, obese children presented with high body dissatisfaction, and this was associated with eating concerns as indicated in the questionnaire. Studies C and D showed that women with AN have a strong preference for underweight bodies, while healthy controls consider slender normal weight most attractive. Moreover, in studies C and D, the discrepancy between the estimated and ideal body, but also the body dissatisfaction questionnaire, were associated with global measures of eating disorder symptoms. Nonetheless, clear differences between body image disturbance in obese children and women with AN emerged.

In obese children, high body dissatisfaction and eating concerns as assessed in study B targeted awareness that being obese is a problem for the individual. Hence, the association between the questionnaire scales and overestimation in obese children despite overall normal performance might be due to the contribution of explicit body representations to the BSE task used. In other words, it is possible that some obese children wanted to illustrate how sure they were of being too big, and therefore exaggerated their size. Moreover, it is not necessarily pathological when obese persons wish to lose weight. Rather, it can be understood as an appropriate reaction which is in line with health recommendations and societal norms, especially considering that the investigated sample was seeking treatment. Hence, it can be concluded that body image disturbance in obesity is a consequence and affliction of obesity, rather than an etiologic or maintaining factor.

By contrast, body dissatisfaction in women with AN was not characterized by a desire to become more healthy and closer to normal, but by a desire to be underweight. Although the investigated women with AN were already in or seeking treatment, and hence were generally motivated to stop dieting, they still expressed a strong preference for being underweight. Further, women with AN felt uncomfortable with their bodies and expressed an ongoing drive to lose weight, despite conscious rational awareness of needing to gain it. The associations between body dissatisfaction as assessed through questionnaires or through BSE and disturbed eating therefore emphasize the important role of body image disturbance in eating behavior in AN. Also, the present results suggest that body image disturbance in AN is a very complex phenomenon.

Implications for concepts of body image disturbance in AN

In terms of concepts of body image disturbance, the current project supplements previous studies suggesting that misestimation of one's body size in eating and weight disorders does not reflect perceptual disturbance (Fernandez-Aranda et al., 1999; Gardner, 2014; Smeets, 1997; Hsu & Sobkiewicz, 1991). Like previous studies, we found no hint that women with AN or obese children have difficulties in visually estimating their size. A possible reason for this could be the reduction of demand characteristics, which were considered in the design of the experiments. All experimental studies had experimenters who were not part of the therapeutic team, carefully worded instructions that did not present any hypothesis, and guaranteed strictly confidential data assessment also in regard to involved clinicians. Studies C and D also enabled indirect insights into propositional distortions that were also discussed as an explanation for overestimation: In both studies, women with AN selected an underweight body as “ideal” and “most attractive”, while controls preferred slender normal weight, suggesting that women with AN indeed have a very different image of an ideal body in mind than controls. Hence, it is likely that the misestimation observed in previous studies was not a secondary effect due to non-average body weight (K. K. Cornelissen et al., 2015) or a visual distortion, but was rather due to propositional representations or demand characteristics.

In regard to body image disturbance in AN and expressed in terms of the present model of body image disturbance, the present project supports partial cognitive-affective disturbance, denies perceptual disturbance and makes no comment on behavioral components. However, the updated framework based on Longo et al. (2010) and Longo (2016) that is introduced in study A suggests a more differentiated conclusion. This framework distinguishes multiple body representations that are active at the same time and that can be classified as perceptual versus conceptual and implicit versus explicit. In this perspective, the present project suggests that it is overly simplistic to speak of disturbed body perception or general cognitive-affective disturbance.

According to the updated framework, umbrella terms such as “perceptual component” cover multiple representations that can be differentially disturbed and mutually influence one another. For example, explicit knowledge of what the body looks like and perceptual sensitivity in visually perceiving body size may be intact, while integration of nonvisual body size cues is disturbed (Gaudio et al., 2014). As different representations interact, it is even possible that, due to attitudes such as being too fat, per se normal perceptual representations such as the sensation of a full stomach are interpreted as indicative of a big belly. Similarly, explicit rational aims of gaining weight can be in conflict with more implicitly desired weight or emotions; and satisfaction with being underweight does not automatically imply satisfaction with the body as a whole. Based on these considerations, it is concluded that basic perceptual processing and explicit knowledge of body size is likely intact in AN. However, women with AN present with conflicting cognitions and attitudes about their body which also seem to impact on higher order processing and integration of body percepts.

Implications for clinical practice

For clinical practice, different conclusions arise from the use of the three components versus the dimensional framework: Within the three-component framework, the present findings suggest that there is no objective perceptual distortion, but a strong cognitive-affective disturbance in the sense of idealized and overvalued underweight. In this theory, therapeutic interventions should focus on cognitive-affective evaluation of the body and on reducing body-checking or avoidance behavior. By contrast, within the dimensional framework the present findings only suggest that there is no hint of explicit visual perception disturbance, but neither allow conclusions on implicit body perception nor on nonvisual body perception. Further, they show that women with AN suffer from incoherent representations such as rational accurate knowledge of their body but conflicting feelings, or rational will to gain weight while at the same time wishing to be underweight, and so forth. According to this interpretation, patients with AN might benefit from interventions that specifically target incongruence between knowledge and experience of the body. Further, as different body representations interact, it might be possible to modify experience of the body by modifying attitudes or emotions and vice versa. This perspective could also serve as a theoretical framework for the investigation of therapeutic progress.

Methodological considerations

The strength of the current project lies in the close link between theoretical considerations and their transfer to experimental designs. By combining an up-to-date theoretical framework with multi-method investigations of persons with eating or weight disorders, novel insights were gained and previous findings were able to be re-evaluated. The more complex model of body image disturbance that is outlined above has the potential to become a useful model for future studies, but also for individual disturbance models. Due to the broad spectrum of patients investigated, the project allowed differences and similarities between body image disturbance to be explored in different diagnostic categories.

Thanks to the innovative methods used, several flaws in previous studies could be corrected, and the data obtained were more informative than in previous designs. In particular, the use of biometric body models in studies C and D represented a substantial improvement on previous approaches. For the first time, it was possible to control exactly the weight manipulations of individualized stimuli, and to forego comparisons with other persons in estimating one's own size. Moreover, the presentation of stimuli in virtual reality in study C elicited high interest in women with AN, as demonstrated by the high participation rates and very positive feedback. Following peer recommendations, it was a strong incentive for participants of study C that they would be offered a realistic impression of how they might look after weight gain. Many participants also showed strong interest in their performance and identified greatly with the more complex model stating that some representations might be distorted while others are accurate. Working with biometric individual body models therefore not only permits methodological advances, but also has the potential to become be a well-accepted medium for therapeutic interventions.

The present project also has several limitations. Firstly, studies B, C and D investigated inpatients only. Inpatients are representative of the patients that many therapists are treating, but they most likely differ from untreated patients in terms of problem awareness and change motivation. More precisely, it is possible that the participants' ambivalence towards their own weight status and the incongruence of several body representations were indicators of initial therapeutic success and not a specific feature of their body image disturbance in general. Secondly, most data in the present project were cross-sectional; only project C incorporated a follow-up assessment of parts of the sample. Hence, the present project did not consider dynamic processes in regard to body image disturbance. Also, although the different studies used multi-method assessment, not all aspects of body representation were covered. Lastly, it should be mentioned that a disadvantage of our innovative methods is that they are not yet established in the field. Partly, this was countered by using parallel procedures to existing setups, but of course replications and further developments would be highly desirable.

Conclusions and further directions

Overall, the present project contributes to a more differentiated and detailed concept of body representation and its disturbance in eating and weight disorders. It supplemented previous literature showing that individuals with eating and weight disorders do not lack awareness of their body weight despite inaccurate estimates reported in previous studies (Cash & Deagle, 1997; Gardner, 2014). While BID in obesity seems to affect cognitive-affective body representations only, the case is more complex in AN. The multi-method approach suggests that different body representations, for example weight perception, weight satisfaction and body satisfaction, are not congruent as regards their content and valence. However, it remains open as to how much this is due to disturbances in isolated representations, or rather to integration processes.

An important next step is to investigate whether women with AN conceptually and affectively interpret visual percepts differently from controls. For example, would women with AN label a normal-weight person "fat", or would they stigmatize normal-weight persons in a similar way to how normal-weight persons stigmatize obese persons? Also, it would be interesting to investigate whether affective responses to certain body weights differ between women with AN and normal-weight women, and if so, whether this effect is limited to their own body or also extends to other persons. Deeper knowledge in respect of these questions could potentially help us to understand the role played by body representation in the development and maintenance of the disorder, and also provide new options when it comes to the identification of high-risk persons and prevention.

In terms of treatment, the potential of virtual reality technology deserves further exploration. A major benefit of virtual reality is that it enables the manipulation of perceived body weight. Through a combination of head-mounted display presentation and upcoming technology, it will soon be possible to manipulate not only visual information about the body, but also haptic feedback. By combining exposure to people's own body in normal weight with other techniques, it could be possible to enhance acceptance of weight-gain therapy and to support cognitive restructuring. To this end, however, it is first of all necessary to solve the technical challenges of such a setup and to explore what type of body weight manipulation is most promising and which body representations should be targeted to maximize efficacy and efficiency. In anxiety disorders, virtual exposure to anxiety-provoking stimuli has shown the potential to be a well-accepted and efficient treatment (Page & Coxon, 2016). Careful adaptation could also open up new perspectives for the treatment of AN.

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Statement of Contributions

Study A) BSE meta-analysis

Mölbert SC, Klein L, Thaler A, Mohler BJ, Brozzo C, Martus P, Karnath HO, Zipfel S, Giel KE. Depictive and Metric Body Size Estimation in Anorexia Nervosa and Bulimia Nervosa: A Systematic Review and Meta-Analysis. *Under review at Clinical Psychology Review.*

This study was designed by **Simone Mölbert**, Katrin Giel and Hans-Otto Karnath with contributions by Stephan Zipfel and Betty Mohler. **Simone Mölbert** searched for studies, screened and rated the search results, collected data from the studies, ran the statistical analysis, generated the figures and tables and drafted the manuscript. Lukas Klein was the second screener and rater, and checked all extracted data for correctness. Anne Thaler and Chiara Brozzo gave input to the updated theoretical framework for body size estimation. Peter Martus advised the statistical analysis of the studies. **Simone Mölbert**, Katrin Giel, Hans-Otto Karnath, Peter Martus and Betty Mohler contributed to the interpretation of results. All authors edited and approved the drafts of the manuscript. **Simone Mölbert** drafted the revisions and **Simone Mölbert** with Katrin Giel wrote the correspondence during the peer-reviewing process.

Study B) BID in obese children

Mölbert SC, Sauer H, Dammann D, Zipfel S, Teufel M, Junne F, Enck P, Giel KE, Mack I (2016). Multimodal Body Representation of Obese Children and Adolescents before and after Weight-Loss Treatment in Comparison to Normal-Weight Children. *PLOS ONE*, *11*(11), e0166826.
http://doi.org/10.1371/journal.pone.0166826

This study was conducted as sub-project of the DROMLIN study (preDictor Research in Obesity during Medical care – weight Loss in children and adolescents during an INpatient rehabilitation) that was designed by Isabelle Mack, Paul Enck, Stephan Zipfel, Dirk Damann and Helene Sauer. Isabelle Mack was principal investigator of the study and managed the study. Helene Sauer assessed all data at the children's hospital in Wangen. **Simone Mölbert** and Isabelle Mack used the final dataset to develop the study questions and to determine the statistic analyses for this manuscript. Isabelle Mack run the statistic analyses, generated the figures, and drafted the sections methods and results. **Simone Mölbert**, Katrin Giel, Stephan Zipfel and Isabelle Mack contributed to the interpretation of results. **Simone Mölbert** wrote the introduction and discussion of this manuscript and she revised and finalized the whole manuscript. All authors edited and approved the drafts of the manuscript. **Simone Mölbert** drafted the revisions and correspondence during the peer-reviewing process.

Study C) BSE in AN using VR

Mölbert SC, Thaler A, Mohler BJ, Streuber S, Romero J, Black MJ, Zipfel S, Karnath HO, Giel KE (2017). Assessing body image in anorexia nervosa using biometric self-avatars in virtual reality: Attitudinal components rather than visual body size estimation are distorted. *Psychological Medicine, Epub ahead of print.* 1–12.
http://doi.org/10.1017/S0033291717002008

This project was conducted as a collaborative project between the Department of Psychosomatic Medicine of the Medical University Hospital Tübigen, the Space and Body Perception research group of the Max Planck Institute for Biological Cybernetics, the Department Perceiving Systems of the Max Planck Institute for Intelligent Systems and the Division of Neuropsychology at the Center of Neurology. Betty Mohler and Michael Black (with colleagues in a previous paper, Piryankova et al. 2014) established the experimental design and stimuli preparation process. Betty Mohler, Katrin Giel, Hans-Otto Karnath, Stephan Zipfel, Michael Black, Stephan Streuber, and **Simone Mölbert** adapted the study design for the patient population. Katrin Giel, Betty Mohler, Michael Black and Stephan Zipfel supervised the study. Javier Romero and Stephan Streuber developed and adapted scripts to align body scans and to generate the weight morphed bodies, and Stephan Streuber generated weight morphed bodies for half of the sample. **Simone Mölbert** took the lead on organizing the contributions from the different departments, recruited and assessed the participants, aligned the scans and generated weight morphed bodies for half of the sample, post-processed all avatars to generate the stimuli for the experiment, analyzed all data and drafted the manuscript including figures and tables. **Simone Mölbert**, Anne Thaler, Katrin Giel, Hans-Otto Karnath and Betty Mohler contributed to the interpretation of results. All authors edited and approved the drafts of the manuscript. **Simone Mölbert** drafted the revisions and correspondence during the peer-reviewing process.

Study D) FRS in AN

Mölbert SC, Thaler A, Streuber S, Black M, Karnath HO, Zipfel S, Mohler B, Giel KE. Investigating body image disturbance in anorexia nervosa using biometric figure rating scales. *Under review at European Eating Disorders Review*

This project was conducted as a side-project to the above described collaborative project between the Department of Psychosomatic Medicine of the Medical University

Hospital Tübigen, the Space and Body Perception research group of the Max Planck Institute for Biological Cybernetics, the Department Perceiving Systems of the Max Planck Institute for Intelligent Systems and the Division of Neuropsychology at the Center of Neurology. This study was designed by **Simone Mölbert**, Anne Thaler, Katrin Giel and Betty Mohler. Stephan Streuber generated the bodies for the figure rating scales, Anne Thaler and **Simone Mölbert** laid out the scales. **Simone Mölbert** assessed about 2/3 of the participants and Anne Thaler assessed the remaining 1/3 of participants. **Simone Mölbert** analyzed the data, generated the figure and tables and wrote the manuscript. Katrin Giel gave input to the figure design. **Simone Mölbert**, Katrin Giel, Hans-Otto Karnath and Betty Mohler contributed to the interpretation of results. All authors edited and approved the drafts of the manuscript. **Simone Mölbert** drafted the revisions and correspondence during the peer-reviewing process.

Manuscripts

Depictive and Metric Body Size Estimation in Anorexia Nervosa and Bulimia Nervosa: A Systematic Review and Meta-Analysis

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Running Head: Body size estimation in AN and BN

Abstract

A distorted representation of one's own body is a diagnostic criterion and core psychopathology of both anorexia nervosa (AN) and bulimia nervosa (BN). Despite recent technical advances in research, it is still unknown whether this body image disturbance is characterized by body dissatisfaction and a low ideal weight and/or includes a distorted perception or processing of body size. In this article, we provide an update and meta-analysis of 42 articles summarizing measures and results for body size estimation (BSE) from 926 individuals with AN, 536 individuals with BN and 1920 controls. We replicate findings that individuals with AN and BN overestimate their body size as compared to controls (*ES*=0.63). Our meta-regression shows that metric methods (BSE by direct or indirect spatial measures) yield larger effect sizes than depictive methods (BSE by evaluating distorted pictures), and that effect sizes are larger for patients with BN than for patients with AN. To interpret these results, we suggest a revised theoretical framework for BSE that accounts for differences between depictive and metric BSE methods regarding the underlying body representations (conceptual vs. perceptual, implicit vs. explicit). We also discuss clinical implications and argue for the importance of multimethod approaches to investigate body image disturbance.

Keywords: body image; body size estimation; anorexia nervosa; bulimia nervosa; eating disorders

Introduction

A distorted representation of one's own body is a diagnostic criterion and core psychopathology of both anorexia nervosa (AN) and bulimia nervosa (BN) (American Psychiatric Association, 2013): despite being of a normal weight or even underweight, patients are convinced that they need to lose weight. This body image disturbance is considered to be a highly relevant factor for both AN and BN (Fairburn, Cooper, & Shafran, 2003; Pennesi & Wade, 2016; Tabri et al., 2015). Despite their relevance in research and clinical settings, the distinctive features of body image disturbance in AN and BN are still unknown. Specifically, it is unclear whether body image disturbance is characterized by body dissatisfaction in conjunction with a low ideal weight and/or includes distorted perception of one's own body size or the bodies of others.

Body size estimation (BSE) tasks were developed to investigate the perceptual component of how individuals perceive their body size, but have not yet yielded conclusive results. In this article, we provide an update and meta-analysis of the literature summarizing measures and results for body size estimations in AN and BN and suggest a revised theoretical framework for BSE. Our revised framework additionally accounts for differences between depictive and metric BSE methods, and clarifies the clinical interpretation of their results.

BSE as a research and clinical tool

BSE tasks were developed in the 1960s and 1970s in pursuit of an objective measure of body perception suitable for the investigation of pathogenic mechanisms in AN (Slade & Russell, 1973). In clinical settings, BSE is commonly used as a therapeutic tool or progress indicator. There are two distinct types of BSE methods to assess visual estimates of self-perceived body size: in depictive methods, participants estimate their body size based on individualized, weight-distorted mirror, photo or video images of their body in standard clothing. Typically, they are asked to select the correct option or adjust the body to their current or ideal body size. Usually, the whole body is presented, therefore depictive methods are also referred to as "whole body" methods (Cash & Deagle, 1997; Farrell, Lee, & Shafran, 2005; Gardner & Brown, 2014). Until recently, depictive methods predominantly used optical distortion techniques, with the distortion often implemented as mere widening or squeezing of a photo in the horizontal dimension. More sophisticated and biometrically plausible distortion methods were developed only recently (Piryankova et al., 2014; Tovée, Benson, Emery, Mason, & Cohen-Tovée, 2003).

In metric methods, participants estimate their size on a spatial measure by indicating the size of different body parts for example with a caliper, a rod or movable markers in a dedicated space in front of them (for example a wall). These distances are then taken in metric units, for example centimeters. In clinical settings, participants usually wear their own clothes and are not hindered from looking down at their body while doing the task, to make the task as naturalistic as possible. Unlike in depictive methods, participants do not express their judgments about pictures of their body, but reproduce their size as distances, with a focus on local spatial estimates and not on the global visual appearance of the body. While depictive methods use percent global distortion as outcome, outcomes in metric methods are measured in metric units, for example as shoulder, breast, or hips width in centimeters. It is customary, but not standard, to determine a whole body estimate as average of the different body part estimates; however, in contrast to depictive methods, this score represents an aggregate of several local estimates and not a global estimate. Therefore, composite whole body estimates may differ from whole body estimates as derived in depictive methods. Metric methods are also referred to as "body part methods" (Cash & Deagle, 1997; Farrell et al., 2005; Gardner & Brown, 2014). Table 1 provides an overview of different BSE methods.

Method	Description	Size	# of included studies	Example
Metric methods				
Image marking	The width of body parts, typically shoulders, waist, hips is indicated by marking their endpoints on a wallpaper	Lifesize	8	Askevold (1975) Uys and Wassenaar (1996)
Movable markers	The width of body parts, typically face, chest, waist and hips is indicated by adjusting movable markers, such as light points or a caliper	Lifesize	14	Slade and Russell (1973) Mizes (1992)
Tape measure	The width or circumference of body parts is indicated by adjusting a tape measure or rod to the estimated size	Lifesize	2	Horne et al. (1991) Schneider (2009)
Depictive Methods				
Photo Distortion	Distorted static photos of the participant in standard clothing are shown and the participants choose or adjust the correct one, or answer whether the respective photos are wider or thinner than themselves	Screen to lifesize	11	Collins (1987) Tovée et al. (2003) Urdapilleta et al. (2007)
Video Distortion	A video of the participants in standard clothing is taken and presented after optical distortion. Some earlier studies distorted optically only using a distorting mirror. Participants are typically asked to adjust their current size.	Screen to lifesize	16	Smeets et al. (1999) Probst et al. (1995) Touyz et al. (1984)

Table 1. Overview on methods used in included studies.

The most commonly used outcome in BSE tasks is the body perception index (BPI) which is calculated according to the formula BPI = (estimated / actual body size) x 100 (Slade & Russell, 1973). Values below 100 indicate an underestimation and values above 100 indicate an overestimation in terms of percent of the actual body size. It is important to bear in mind that the BPI is a relative measure standardized to the individual's size; hence, the same absolute overestimation would result in a higher BPI when actual body size is smaller. However, switching to absolute units has not been found to improve the clarity of results (Smeets, Smit, Panhuysen, & Ingleby, 1998).

On a theoretical level, BSE tasks have so far usually been discussed in the context of the “dual model” framework of body representations (Cash & Deagle, 1997; Farrell et al., 2005; Gardner & Brown, 2014). Generally, models in this framework distinguish between an action-serving representation often labeled as *body schema* and a representation serving perception of the own physical appearance, attitudes towards one’s body and conceptual issues, often called *body image* (de Vignemont, 2010). As yet, BSE research has generally been motivated by the assumption that a perceptual distortion of body image, namely an overestimation of the self-perceived body size in the mental picture of the own body, may foster body dissatisfaction and may be a pathology mechanism of AN and BN (Farrell et al., 2005; Gardner, 1996; Gardner & Brown, 2014).

A major flaw of this framework is the inconsistency in how different models belonging to it conceptualize body image and interpret BSE: some authors, typically in neurology and cognitive neuroscience, define body image as a mental picture of the body and thereby mainly perceptual (Paillard, 1999). Others, typically in the eating disorder literature, suggested a sub-division into a perceptual and an attitudinal component (Gadsby, 2017; Gardner & Bokenkamp, 1996), or even in a system of perceptual component, attitudinal component and cognitions (Gaudio & Quattrocchi, 2012). Consequently, BSE was usually interpreted as being indicative for a perceptual distortion, although this was not properly defined and several studies suggested there might not be a perceptual distortion at all (Fernandez-Aranda, Dahme, & Meermann, 1999; Gardner & Bokenkamp, 1996; Smeets, 1997; Smeets, Klugkist, Rooden, Anema, & Postma, 2009). Generally, suitability of the “dual model” framework as appropriate structure for studying body representation has been questioned (de Vignemont, 2010). To overcome this conceptual confusion, this study re-analyzes previous studies within an updated theoretical framework

(Longo, 2015, 2016; Longo, Azañón, & Haggard, 2010) that is sensitive to the aforementioned distinction between perceptual and attitudinal components of body representation distortion, as well as to the extent to which the distorted body representations are implicit versus explicit.

Previous BSE findings in patients with AN and BN

So far, empirical evidence on performance of patients with AN and BN in BSE tasks is very heterogeneous and partly inconclusive. In an earlier meta-analysis of measures assessing body image disturbance, a moderate overestimation effect in both AN and BN patients was found (Cash & Deagle, 1997). Further, Cash and Deagle (1997) found larger effects for depictive methods than for metric methods. In a subsequent review, Farrell et al. (2005) replicated the overestimation finding, but due to the validity problems that they assigned to most methods, they concluded that the significance of this overestimation is unclear. Importantly, Farrell et al. (2005) emphasize that validity problems did not only concern technical challenges of the experimental setups limiting ecological validity, but also a lack of theoretical concepts about what exactly the different BSE tasks assess. It is obvious that BSE recruits not only size representations, but potentially also memory, proprioception, cognitions and so forth.

More recent reviews report that subsequent research focused on solving the problem of ecological validity by improving BSE assessment methods while conceptual problems of BSE remain unsolved. As Gardner and Brown (2014) report in a recent review focusing only on individuals with AN, advanced photo distortion technique was the most common assessment method in recent publications. While Gardner and Brown (2014) report a trend for more homogeneous results finding overestimation in adult individuals with AN, Legenbauer, Thiemann, & Vocks (2014), on the other hand, found very heterogeneous results for children and adolescents with AN. To our knowledge, there are no follow up reviews involving BN patients. In summary, while the moderate general effect of body size overestimation in individuals with AN and BN seems to be a robust finding, it is still unclear whether this originates from perceptual distortions of the self-perceived body size or from attitudinal processes. In the meantime, however, theoretical advances of body representation frameworks allow for a more differentiated conceptualization of BSE tasks, and comparisons of estimates in different conditions might reveal insights into the meaning of overestimation.

Revisiting the theoretical framework of BSE

Recently, Longo suggested a new framework of body representations that includes body image and body schema among multiple other body representations (Longo, 2015, 2016; Longo et al., 2010). This framework is based on a neuroscientific perspective and encompasses sensory processing as well as higher order concepts of and about the body. It comprises multiple distinct body representations that are informed by different sensory modalities and can be arranged along two orthogonal axes. One of these axes represents how perceptual versus conceptual the representation appears to be, thereby retaining the traditional notion of the dual model (Longo, 2015). According to the framework, body representations that were previously classified as body schema or perceptual body image are located at the perceptual end of the dimension, and summarized under the term "somatoperception". Representations in the cognitive-affective body image domain fall at the conceptual end of the continuum, and are summarized under the term "somatorepresentation". The second dimension specifies how implicit versus explicit the representation is, that is, how easily it can be accessed by conscious introspection. Notably, the model assumes that multiple body representations can be active at the same time, but may be recruited more or less by specific tasks.

Although Longo's framework was initially developed for research on somatosensory processing, the authors subsequently used and revised it for the investigation of BSE tasks. Longo & Haggard (2012) concluded that metric and depictive BSE methods differ in how implicit or explicit the recruited representations are: Depictive methods might address explicit representations, namely what the participants think their body looks like. Metric methods could be located in the middle of the continuum, because they may also recruit implicit representations of one's width, depth, length, like they are also used for motor action. In other words, although metric methods require participants to provide an explicit visual estimate of their body size, they may additionally recruit more implicit body representations, for example from proprioception. As a consequence, systematic differences in BSE between the methods could indicate whether overestimation is rather driven by distortions in explicit or in implicit representations.

Regarding the perceptual versus conceptual dimension, it is currently unclear where to locate depictive versus metric methods best within Longo's framework. Although Longo (2015b) defines the body image as a perceptual representation not influenced by attitudinal factors, it has already been shown that attitudes towards one's own body can influence size estimation differently in individuals with eating disorders compared to controls (Cash & Deagle, 1997; Gardner, 1996; Hsu & Sobkiewicz, 1991; McCabe, Ricciardelli, Sitaram, & Mikhail, 2006; Smeets, Ingleby, Hoek, & Panhuysen, 1999). Also, the focus of the instruction on the "felt" versus "known" size can influence size estimates (Bowden, Touyz, Rodriguez, Hensley, & Beumont, 1989). Consequently, BSE tasks appear to assess a broad range of perceptual and conceptual representations, with the relative proportions remaining unclear in respect to study context and sample. For example, as physical appearance is central to the self-evaluation in individuals with eating disorders, BSE may activate more conceptual representations such as feelings and attitudes towards the body in individuals with AN and BN than in controls. Hence, the same BSE task could be more conceptual for individuals with an eating disorder than for healthy controls. Individuals with AN or BN would then overestimate their size not because they perceive the body differently, but because BSE in individuals with eating disorders assesses attitudes more than perception. Consequently, average differences in attitudes towards the body between different eating disorders should be reflected in BSE. Figure 1 illustrates the classification of BSE tasks within this revised BSE framework.

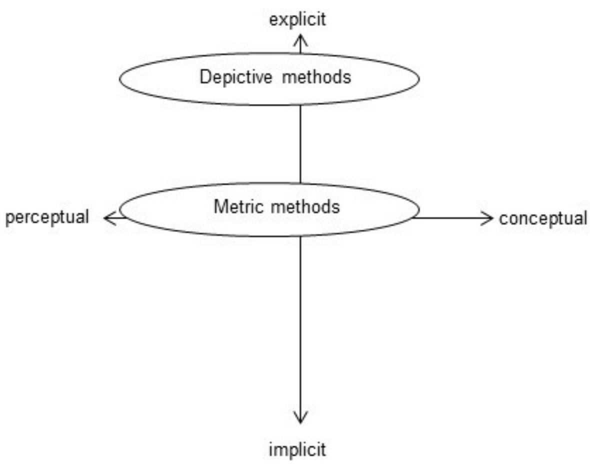

Figure 1The revised framework of BSE is based on a body model proposed by Longo (2016) in which two axes organize body representations depending on how perceptual or conceptual they are, and how implicit or explicit. Any given body representation will be located

Objectives of the present study

The present article aims to provide an updated review and meta-analysis on BSE tasks in both individuals with AN and BN. Unlike recent reviews, we integrate a meta-analysis of the results to investigate differences between the two eating disorders and between studies using depictive versus metric methods for estimating body size. Our objectives are to investigate a) whether patients with AN and BN overestimate their body size compared to control participants and how large the overall effect size is in current literature. Further, we use Longo's framework to investigate what type of body representations could drive mis-estimation in AN and BN by analyzing b) whether the degree of overestimation varies between patients with AN and BN and c) whether the degree of overestimation depends on the used method (depictive versus metric). In this context, we also consider to what extent the body representations involved in depictive vs. metric BSE are conceptual versus perceptual, and implicit versus explicit. We discuss implications for clinical practice and further research.

Methods

A systematic literature search was conducted according to PRISMA guidelines for systematic reviews and meta-analyses (Liberati et al., 2009; Moher, Liberati, Tetzlaff, & Altman, 2009).

Electronic Searches

We searched the databases PubMed and PsycInfo for literature published up to October 2016 on body schema or body image distortions. For PubMed, the search terms used in the general search were "body schema distorted/distortion/distortions" or "body schema size estimation". Since Medical Subject Headings (MeSH terms) for "body schema" were also included in the search, these keywords also covered combinations with the terms "body image" and "body representation". We narrowed the search to articles examining "Humans". The full search path for PubMed (not considering the restrictions) is [("body image"[MeSH Terms] OR ("body"[All Fields] AND "image"[All Fields]) OR "body image"[All Fields] OR ("body"[All Fields] AND "schema"[All Fields]) OR "body schema"[All Fields]) AND (distortion[All Fields] OR distorted[All Fields] OR distortions[All Fields]) OR (("body image"[MeSH Terms] OR ("body"[All Fields] AND "image"[All Fields]) OR "body image"[All Fields] OR ("body"[All Fields] AND "schema"[All Fields]) OR "body schema"[All Fields]) AND size[All Fields] AND estimation[All Fields])]. For PsycInfo, we used the equivalent search terms, using the Boolean search term [(body schema OR body image OR body representation) AND (distortion OR distorted OR distortions OR (size estimation))]. Again, we narrowed the search to human populations.

In addition, review articles were examined for relevant citations (Cash & Deagle, 1997; Farrell et al., 2005; Gardner & Brown, 2014), the *Journal of Eating Disorders* and *Body Image* were searched manually and *The International Journal of Eating Disorders* was searched manually from 1996 on to locate any additional studies.

Eligibility criteria

We included studies in the analysis if they met the following criteria: (1) Peer-reviewed journal article; (2) Language English, French or German; (3) Examination of adult individuals with AN or BN (no mixed eating disordered group) and control participants. AN or BN had to be defined according to classification systems that were up-to-date at the time of the study and controls had to be non-eating disordered; (4) reports results of a BSE task; (5) sample sizes, primary diagnosis, group mean of body perception index and standard deviation for whole body or body parts provided or derivable.

Studies were regarded as questionnaire surveys and not as BSE tasks if participants gave ratings on non-individualized material (as in figure rating tasks) or if the task was conducted as a structured interview in which predefined questions were read aloud and answers were recorded per to a predefined rating scheme. Methods were considered as BSE tasks if participants estimated their size based on their imagined own body or based on individually distorted visualizations of them. Reviews, meta-analyses, comments and letters to the editor were not included.

Study selection procedure

First, search results were imported into Endnote X7.1 and duplicates were removed. Afterwards, SCM and LK screened publications by title and abstract to remove articles that clearly did not meet eligibility criteria. At this step, we excluded articles only if both examiners assessed them to be irrelevant. Third, we obtained full texts of potentially relevant reports and both raters independently examined articles to determine whether they met eligibility criteria. Disagreements about study eligibility occurred for instance when due to complex study designs it was unclear which of the reported measures corresponded best to the measures reported in other studies. These disagreements were discussed and, if no immediate consensus was obtained, a third independent rater made a judgment about inclusion and rules were defined on which data to extract.

Data collection

We extracted the following data from the eligible studies: (1) sample sizes; (2) primary diagnose of patient sample; (3) type of BSE task used (depictive methods: photo or video distortion; metric methods: movable markers, tape measure, image marking); (4) mean BPI and standard deviations of each group for all reported body estimates. SCM and LK performed data extraction and data evaluation. In longitudinal and experimental studies, baseline performance was extracted. Some studies investigated the influence of different instructions on BSE (e.g. “How do you feel you look like?” versus “How do you think you look like?”).

In these studies, we extracted the results for the most neutral instruction and if not applicable, for the most cognitively-focused instruction (i.e. for the "think" instruction and not for the "feel" instruction). In case of different control groups, the least preselected one was used (e.g. when anorexia nervosa patients were compared to restrained eaters and unrestrained eaters, values for unrestrained eaters were chosen). When a study examined several patient groups or used several methods, each of the group-wise comparisons for the respective methods and patient groups were extracted and all outcomes included into the analysis. If mean BPI and standard deviations for patient or control group were not explicitly reported but could be derived from the data provided (e.g. when raw data was presented or standard errors instead of standard deviations were reported), the authors performed calculations and the results were extracted.

Seven studies used metric methods and did not report a composite BPI for the whole body. While a post-hoc calculation of composite mean BPI could be performed based on the reported body part estimates, computation of the composite standard deviation was problematic: Computing the standard deviation of a sum of correlated terms requires knowledge of the correlations between the measures, in our case between the body part estimates. As most studies did not report correlations between body part estimates, a post-hoc calculation of whole body BPI was in part speculative. We still exploratively estimated these covariances based on pooled correlations between body part estimates for patient and control groups derived from all available correlation matrices (Button, Fransella, & Slade, 1977; Pierloot & Houben, 1978; Slade & Russell, 1973). However, all studies used to estimate the correlations investigated patients with AN, used movable markers methods, and reported different correlations for patients with AN and controls, suggesting that it might not be justified to transfer correlations from one group to another. Out of the nine analyses without composite BPI, only four were alike, the other five ones analyzed patients with BN. Three out of this five studies additionally used different body sites and one even used another metric method. We therefore did not include these post-hoc whole body BPI estimates in the meta-analysis, but only exploratively re-ran the meta-analysis including them and presented the results in terms of a sensitivity analysis.

Analysis of single studies

An overview of studies was obtained in a standardized way by computing Hedge's *g* as a measure of effect size for each reported group comparison and performing t-tests to test whether the respective group comparisons were statistically significant. Study characteristics and main findings were then summarized in Table 2.

Meta-analysis of studies reporting whole body BPI

As listed in Table 2, 35 (86%) of the studies reported BPI for the whole body, either directly derived (depictive methods) or as a composite score from body part estimates (metric methods). On these data, we performed a meta-analysis using R statistics software with package metafor (Viechtbauer, 2010). We accounted for clustered data structure using article as outer factor and assessment method (video distortion, photo distortion, image marking, movable markers, tape circumference) as inner factor. Following Borenstein, Hedges, Higgins, & Rothstein (2009) we tested: (a) whether patients overestimate their body size compared to control participants, (b) whether the degree of overestimation varies between patients with AN and BN, and (c) whether accuracy of BSE depends on the method category used (depictive versus metric method). First, we performed a random effects meta-analysis to obtain a general estimate of overall effect size. In a second step, we performed a meta-regression using a random-effects model with "patient diagnosis” and “assessment method” as moderators to explore whether they are meaningful moderators of effect size. Additionally, we performed a random-effects meta-regression on BPI measures of control participants only using method category (depictive versus metric) as a moderator to check for baseline differences between the method categories, as suggested by Longo & Haggard (2012). In this analysis, we excluded double records due to multiple patient samples within one study, however modeled the clustered data structure with article as outer factor and assessment method as inner factor.

Results

Study selection

Our search in electronic databases yielded 1836 hits, 27 records were additionally identified through handed search. We eliminated 231 duplicates and discarded 1273 articles after reviewing title and abstract. The remaining studies were rated and 317 articles were excluded because they did not fulfil the eligibility criteria. 42 studies met all eligibility criteria and were included. Figure 2 illustrates the study selection process in detail.

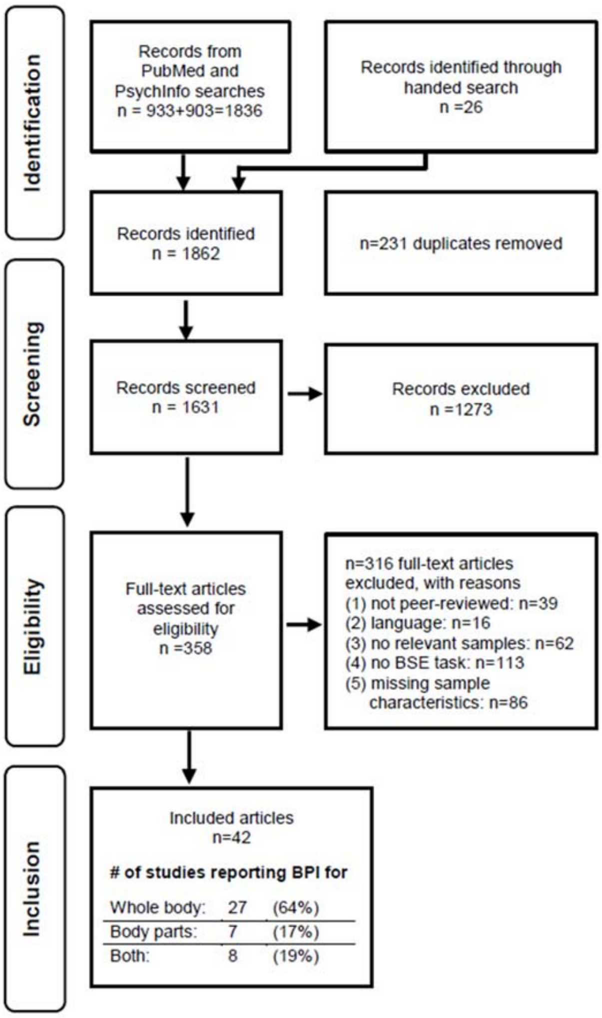

Figure 2. PRISMA-Flowchart of the study selection procedure.

Study characteristics

Table 2 provides an overview of the included studies and their results. All included studies investigated women only. In recent years, photo distortion was the most commonly used method to assess BSE, continuing away from the trend of body part methods towards whole body methods. Generally, if studies found a significant difference between patient and control participant BPI, patients always had larger BPI compared to controls, supporting the overestimation findings of previous studies.

					patients' BPI compared to controls					
Article	n AN patients	n BN patients	n Controls	Body Size Estimation Method	whole body	Face	shoulders	chest	waist	hips
Hagman et al. (2015)	74		11	photo distortion	>					
Øverås et al. (2014)	37		35	photo distortion	>					
Mohr et al. (2010)	16		16	photo distortion	n.s.					
Schneider et al. (2009)	75		268	tape measure	>				n.s.	
Urdapilleta et al. (2007)	22		22	photo distortion	n.s.					
Vocks et al. (2007)		30	55	photo distortion	>					
Tovée et al. (2003)	30		137	photo distortion	n.s.					
		30	137	photo distortion	n.s.					
Smeets et al. (1999)	30		36	video distortion	>					
Hennighausen et al. (1999)	36		18	photo distortion	n.s.					
Kulbartz-Klatt et al. (1999)		40	40	video distortion	n.s.					
Szymanski and Seime (1997)		20	20	video distortion	>					
Probst et al. (1997)		38	45	video distortion	>					
	34		45	video distortion	>					
	87		45	video distortion	n.s.					
Uys and Wassenaar (1996)	11		51	image marking	n.s.		n.s.		>	n.s.
Probst et al. (1995)	53		36	video distortion	n.s.					
		38	36	video distortion	n.s.					
Mizes (1992)	8		11	movable markers	n.s.					
		15	11	movable markers	n.s.					
Probst et al. (1992)	67		105	video distortion	n.s.					
Horne et al. (1991)		55	61	tape measure	>			>	>	n.s.
Bowden et al. (1989)	12		24	movable markers	>					
	12		24	image marking	>					
	12		24	video distortion	n.s.					
		12	24	movable markers	n.s.					
		12	24	image marking	>					
		12	24	video distortion	n.s.					
Franzen et al. (1988)		15	15	video distortion	n.s.					
Lindholm and Wilson (1988)		12	12	video distortion	>					
Mizes (1988)		20	20	movable markers	>					
Nudelman et al. (1988)		20	20	movable markers	>					
Gardner and Moncrieff (1988)	9		9	video distortion	n.s.					
Whitehouse et al. (1988)	12		20	image marking	n.s.		n.s.		>	n.s.
	12		20	video distortion	n.s.					
Willmuth et al. (1988)		20	20	movable markers	>					
Gleghorn et al. (1987)		55	55	photo distortion	>					
		55	55	image marking		n.s.	>		>	>
		55	55	movable markers		n.s.	>		>	>
		55	55	movable markers		n.s.	>		>	>
Collins (1987)	25		50	photo distortion	n.s.					
Proctor and Morley (1986)	24		30	movable markers		>		>	>	>
Whitehouse et al. (1986)		22	20	image marking	>		n.s.		>	>
		22	20	video distortion	>					
Willmuth et al. (1985)		20	20	movable markers				>	>	>
Freeman et al. (1985)		24	33	video distortion	>					
Touyz et al. (1984)	15		15	video distortion	n.s.					
Meermann (1983)	36		35	image marking	n.s.	n.s.	n.s.		n.s.	n.s.
	36		35	video distortion	>	>				
Garfinkel et al. (1983)	23		12	video distortion	>					
Strober et al. (1979)	18		24	image marking	n.s.		n.s.		n.s.	n.s.
Casper et al. (1979)	79		130	movable markers		n.s.		n.s.	>	
Garfinkel et al. (1978)	26		16	photo distortion	n.s.					
Pierloot and Houben (1978)	31		20	image marking	>		n.s.		>	n.s.
	31		20	movable markers	>	>			>	>
Button et al. (1977)	20		16	movable markers		n.s.		n.s.	n.s.	n.s.
Garner et al. (1976)	18		16	photo distortion	>					
Slade and Russell (1973)	14		20	movable markers		>		>	>	>

Table 2. Sample sizes, body size estimation method and reported group comparisons of body perception index from included studies. > and < denote a significantly larger or smaller Body Perception Index of patients as compared to controls at .05 level (t-test), n. s. denotes reported but non-significant differences between groups. References of included studies are provided in the supplement (A).

Body part estimates

Studies that used metric methods mostly investigated waist, hips, either shoulder or chest, and face width (Table 2). In 70% of the metric studies, estimates were aggregated and a composite BPI score was reported for the whole body. Only six studies reported no BPI for the whole body, another study did not report a composite whole body BPI for body part methods, but provided a whole body estimate based on photo distortion. The most consistent significant difference between patient and control BPI was found for the waist, where 72% of group comparisons report a significant group difference. For the shoulder width, only 33% of group comparisons yielded a significant difference between patients' and controls' estimates. Pooled correlations between face, chest, waist and hips estimates ranged between r = .67 and r = .85 in individuals with AN and between r = .54 and r = .84 in controls, suggesting that generally, aggregation to a composite whole body BPI is justified. Shoulder size estimates, however, correlated more weakly with other body part estimates (between r = .50 and r = .59 in individuals with AN and between r = .25 and r = .81 in controls).

Meta-Analysis of whole body BPI

The random-effects model estimated the pooled effect size of all studies reporting group means of whole body BPI to be ES = 0.63 (CI [0.49-0.78], p < .001), which can be interpreted as an overall moderate effect in the sense that patients with AN and BN overestimate their body size as compared to controls. However, there was significant moderate heterogeneity in effect sizes ($Q(df = 49)$ =135.69, p < .001), indicating that effect sizes vary systematically across the studies (Higgins, Thompson, Deeks, & Altman, 2003).

As the meta-regression showed, the proposed moderators "patient diagnosis" and "assessment method category" accounted together for a significant proportion of heterogeneity among effect sizes in group comparisons ($Q_{Mod}(df = 2)$ = 17.31, p < .001). Specifically, in comparison with studies investigating patients with AN and using a depictive method (d_{AN_dep}=0.45, CI [0.28; 0.61], p < .001), studies using a metric method yielded larger effect sizes (β_{metric} = 0.40, *CI* [0.16; 0.63], $p<.01$) and studies investigating patients with BN yielded larger effect sizes (β_{BN} = 0.21, *CI* [0.03;0.41], $p<.05$). Interactions were not considered in the model. Residual heterogeneity in effect sizes was still moderate ($Q_E(df = 47) = 94.91$, $p<.001$). The forest plot (Figure 3) provides an overview about the effect sizes of the different studies and subgroups. The funnel plot (Figure 4) shows a symmetric distribution of standard errors, indicating that publication bias is likely to be absent in the analyzed studies.

Two explorative meta-regressions were performed with post-hoc estimated composite whole body BPI for studies that had not reported whole body estimates. In a first step, we included only four additional studies that matched our data base for pooled correlations between body part estimates as they investigated individuals with AN and used movable markers as method. In this analysis, the overall effect increased to ES = 0.65 (CI [0.50; 0.80]) with no considerable change in moderator effects. In addition, we included five more data sets from two other studies investigating individuals with BN, one of them with an image marking method. In this analysis, the overall effect size remained ES = 0.65 (CI [0.50; 0.80]), but the moderator effects were no longer significant (all p >.10). Hence, while the overall effect size was very robust, the significance of the moderator effects was sensitive to the study selection.

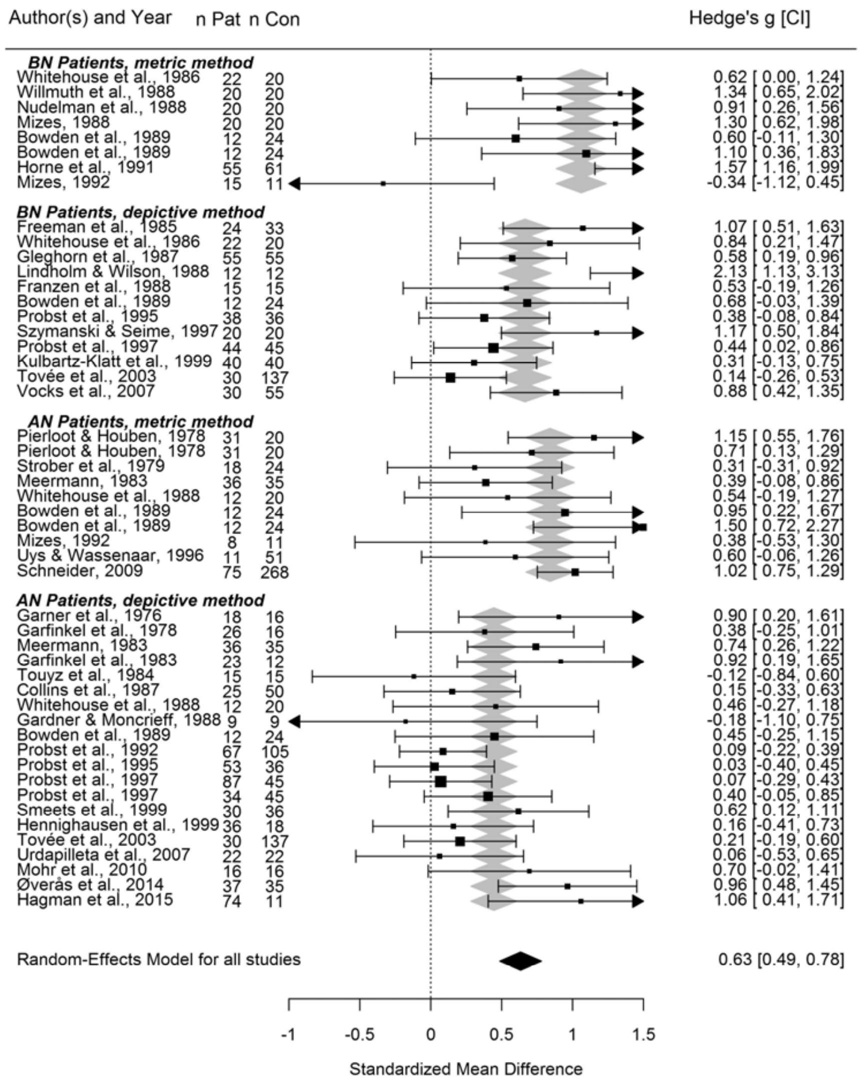

Figure 3. Sample sizes for patient and control group, effect sizes Hedge's g and confidence intervals (CI) of effect sizes for group comparisons of whole body perception indices. The overall effect size from the random-effects meta-analysis is depicted by a black diamond, estimated effect sizes for the combined factors from the meta-regression are depicted as grey diamonds.

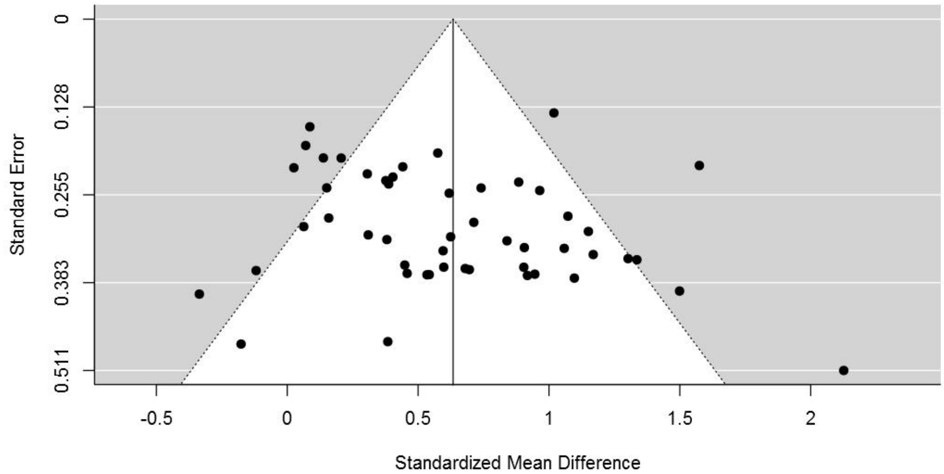

Figure 4. Funnel plot for included studies.

Further, we analyzed the absolute BPI of control participants in a separate random effects meta-analysis and meta-regression. Through this, we obtained an average BPI for control participants, and could evaluate whether healthy people are also generally less accurate in metric methods than in explicit methods, as suggested by Longo & Haggard (2012).We found that on average, control participants are accurate in estimating their body size (BPI_{est}=100.20, CI [94.40; 106.00], Q(39)=12266.56, *p*<.001). Assessment method category was a significant moderator of effect size. Confidence intervals of intercept and moderator weight show that already healthy people are accurate in depictive methods while they overestimate in metric methods (BPI_{dep}=95.80, CI [89.74; 101.86]; β_{metric}= 14.33, CI [6.90; 21.75], *p*<.001; Q_{Mod}(1)=14.28, *p*<.001; Q_E(38)=11153.30, *p*<.001).

Discussion

Like previous reviews, we observed a robust mean effect of *ES*=0.63 for whole body estimates, reflecting a moderate overestimation of self-perceived body size in individuals with AN and BN compared to controls (Cash & Deagle, 1997; Farrell et al., 2005; Gardner & Brown, 2014). Interestingly, our meta-regression shows that the factors “assessment method category” (depictive versus metric) and potentially “eating disorder diagnosis” (AN versus BN) significantly moderate effect sizes. Effect sizes were found to be larger in BN than in AN, and self-perceived body size was overestimated more when metric methods were used than when depictive methods were used. Within the revised theoretical framework for BSE this suggests that body size overestimation is not driven by a perceptual distortion, but rather by distorted implicit representations and conceptual representations.

We used our meta-regression on controls’ estimates to evaluate whether it is appropriate to transfer Longo and Haggard’s (2012) considerations on classification of BSE tasks from hand size estimates to estimates of the whole body. Importantly, in our meta-regression of control participants’ performance, we observed the same pattern that Longo and Haggard (2012) report for the hand size estimates: While in depictive methods, controls were accurate in estimating their size, we found controls to clearly overestimate in metric methods. As this replicates Longo and Haggard (2012), we conclude that metric methods likely assess not only explicit knowledge about the body size, but also implicit representations.

In our meta-regression of effect sizes from eating disorder versus control group comparisons, we found that metric assessment methods produce larger effect sizes than depictive methods. Following our revised framework, this indicates that body image disturbance may not be as much an issue of explicit body representation but rather of implicit body representation. This interpretation is in line with recent evidence showing impairments in somatosensory and proprioceptive tasks in individuals with AN. According to this research, individuals with AN and BN would have no visual misperception of their body, but difficulties in generating a coherent self-perceived body representation arising from distortions in more implicit representations (Case et al., 2012; Keizer et al., 2013; for a review see Gaudio et al., 2014;).

Regarding the perceptual versus conceptual classification of body representation, we propose both the moderator effect of eating disorder diagnosis and the review of body part wise results from metric methods are informative . Given the broad confidence interval and the sensitivity analysis, we interpreted the moderator effect of eating disorder diagnosis carefully. We found no evidence that individuals with AN generally overestimate more than individuals with BN, as suggested by recent research (K. K. Cornelissen, Bester, Cairns, Tovée, & Cornelissen, 2015; P. L. Cornelissen, Johns, & Tovée, 2013; Moscone, Amorim, Le Scanff, & Leconte, 2017). However, our results agree with this line of research insofar as we also conclude that visual perception is likely not generally disturbed in eating disorders. If individuals with BN were to overestimate more than individuals with AN, this would mirror findings on conceptual body representations, particularly attitudes. It has been shown that individuals with BN have higher drive for thinness and body dissatisfaction than individuals with restrictive AN (Garner, Olmsted, & Polivy, 1983; Paul & Thiel, 2005). Consistent with this hypothesis, we found that in metric methods, overestimation was most consistent for body parts that are emotionally salient for individuals with an eating disorder, such as the waist and hips. Moreover, it has been shown that in mirror scenarios, individuals with AN and BN have an attentional bias towards the body parts that they are least satisfied with compared to healthy controls (Tuschen-Caffier et al., 2015). We therefore consider it likely that conceptual representations (explicit or implicit), in the form of attitudes towards the body, influence BSE estimates, especially in individuals with an eating disorder.

Methodological imitations

Methodological limitations of this review arise from our study selection process as well as from the included studies. As we only searched for published results, a publication bias towards significant effects cannot be excluded. Although the funnel plot showed a symmetric distribution of effect sizes, our results could still be an overestimation of the true effect size. Moreover, our explorative meta-analysis with estimated composite whole body BPI for studies that did not report it suggested that the moderator effects of eating disorder diagnosis and method category might not be robust. Further, as terminology in the field is very heterogeneous, it is possible that despite our broad search strategy, we missed relevant articles. To encounter problems arising from study heterogeneity, we also limited our search to studies reporting their results in terms of BPI (or convertible), thereby excluding studies with different, but potentially related outcomes. Notably, some of the included studies had small sample sizes and may have been underpowered. In addition, procedures varied considerably in how they quantified the percentage of mis-estimation. For example, while many metric measures use average indicated width in centimeters, depictive methods can rely on optical properties or even pixel counts. Unfortunately, as studies were very heterogeneous in if and how they reported attitudes towards one's body, we were also not able to include attitudes as a potential moderator in our quantitative analysis.

Conclusions and further directions

In this systematic review and meta-analysis, we replicated the finding that individuals with AN and BN overall moderately overestimate their body size (*ES*=0.63), and observed that this effect is moderated by BSE assessment method and potentially by eating disorder diagnosis. To clarify the reasons behind this overestimation, we interpreted these results in the light of Longo's framework of body representation (Longo, 2015). According to this model, the traditional notion of BSE targeting the mental picture and visual perception of the body applies to depictive methods only, while metric methods may additionally assess more implicit representations.

Our meta-analysis emphasizes that while perceptual representations are plausibly involved in both depictive and metric body size estimation, it is not adequate to generally interpret body size estimates as measures of "perceptual distortion" or "visual distortion" (Cash & Deagle, 1997; Farrell et al., 2005; Gardner & Brown, 2014; Slade & Russell, 1973). Rather, even the purportedly simple BSE tasks assess an integration of several body representations. It may depend on task characteristics, and also on the participants themselves as to which representations are targeted by the respective task. Hence, overestimation findings are unlikely to reflect only a disturbed visual body perception, as has been stated previously (Farrell et al., 2005; Gardner & Brown, 2014). To better understand body image disturbance in AN and BN, it is necessary to investigate the different types of body representation and their interplay in multi-method approaches.

In particular, as effect sizes were larger for metric methods, and in light of recent findings that suggest distorted implicit representations (Gaudio et al., 2014), we assume that within the perceptual component of body image disturbance, implicit body representations may be impaired to a larger extent than explicit body weight representation. Furthermore, we discussed that BSE is not a pure measure of body perception, but also involves conceptual representations such as attitudes towards the body.

We see a major challenge for further research in investigating which body representations are assessed by different tasks, and what role different body representations play in eating disorders. Specifically, regarding the perceptual component of body image disturbance, further research is needed that targets implicit body representation and how those representations interact with explicit perceptual and cognitive-affective body representations. For example, combining BSE with tasks involving somatosensation, affordances, or actions (cf. Gaudio et al. (2014) for a review) could help to shed light on the interplay between different types of body representations and their disturbances in eating disorders.

The lack of adequate etiologies in eating disorders is considered a significant hurdle in the development of more effective therapies (Pennesi & Wade, 2016; Schmidt & Campbell, 2013). Specific exposure therapies targeting body perception have already been tentatively developed, but so far usually address body dissatisfaction, body checking, and avoidance (Koskina, Campbell, & Schmidt, 2013). In pursuit of a mechanism-oriented psychotherapy, it is crucial to understand more about the contributions of a distorted mental image of the body and other, potentially implicit body representations to body image disturbance. In addition, it would benefit the field to better understand the relationships between distorted body representations and other cognitive and affective disturbances in eating disorders, such as social processing, reward processing and emotionality (Caglar-Nazali et al., 2014; Lavender et al., 2015; O'Hara, Campbell, & Schmidt, 2015).

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BSE in AN and BN - Appendix A

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RESEARCH ARTICLE

Multimodal Body Representation of Obese Children and Adolescents before and after Weight-Loss Treatment in Comparison to Normal-Weight Children

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Abstract

Objective

The aim of the study was to investigate whether obese children and adolescents have a disturbed body representation as compared to normal-weight participants matched for age and gender and whether their body representation changes in the course of an inpatient weight-reduction program.

Methods

Sixty obese (OBE) and 27 normal-weight (NW) children and adolescents (age: 9–17) were assessed for body representation using a multi-method approach. Therefore, we assessed body size estimation, tactile size estimation, heartbeat detection accuracy, and attitudes towards one's own body. OBE were examined upon admission and before discharge of an inpatient weight-reduction program. NW served as cross-sectional control group.

Results

Body size estimation and heartbeat detection accuracy were similar in OBE and NW. OBE overestimated sizes in tactile size estimation and were more dissatisfied with their body as compared to NW. In OBE but not in NW, several measures of body size estimation correlated with negative body evaluation. After weight-loss treatment, OBE had improved in heartbeat detection accuracy and were less dissatisfied with their body. None of the assessed variables predicted weight-loss success.

Conclusions

Although OBE children and adolescents generally perceived their body size and internal status of the body accurately, weight reduction improved their heartbeat detection accuracy and body dissatisfaction.

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Introduction

Childhood obesity is increasing worldwide, and it is associated with both psychosocial and medical complications [1, 2]. Awareness of the problem and motivation are considered a key factor in changing health behavior [3, 4]. In this sense, it has been suggested that a lack of awareness of the own body size or indifference towards own weight status contribute to overweight, as they hamper motivation for weight loss [5–7]. In addition, it has been suggested that a disturbed interoceptive processing, as indicated by poor heartbeat detection accuracy, might contribute to an excessive food intake [8, 9]. As yet, no study has comprehensively investigated different types of body representation in obese children and adolescents. It is still unclear whether obese children and adolescents really have a disturbed body representation and whether weight loss also involves changes in body representation that could be addressed in weight loss treatment.

Body representation is not uniform, but a conglomerate of multiple body representations that are informed by different modalities [10, 11]. In this notion, body representation comprises not only attitudes about body weight and shape, but also a mental picture of one's own body and implicit representations informed by proprioception, somatosensation and interoception. It is assumed that different body representations are organized along a continuum between implicit and explicit representations [12].

Studies on childhood obesity have typically focused on explicit body representation only and mostly used cross-sectional designs. It has been shown that a significant proportion of overweight children tend to underestimate their current body size in figure rating scales [13, 14], though this has not been replicated in adults when using methods that have a less social focus [15]. Also, children and adolescents with a high body mass index (BMI; kg/m^2) tend to have high body dissatisfaction and low self-esteem, contradicting the idea that the problem of obesity is often ignored [1, 13, 16]. Longitudinal studies, suggested that both body dissatisfaction and body size estimation in figure rating tasks approach performance of normal-weight children when overweight is reduced [17–19].

Recently, more implicit types of body representation came into the focus of obesity research and reopened the debate again. Heartbeat detection accuracy has been observed to be diminished in adults with high BMI [20] and it is associated with healthier eating behavior and better physical fitness in children [9, 21]. Also, studies in adults indicate that participants with high BMI might have difficulties in estimating the size of an object touching their skin (tactile size estimation), possibly reflecting a disturbed sense of the own size [22–24]. Taken together, while the observed disturbances in explicit measures of body representation could be interpreted as effect of social teasing and stigmatization, implicit measures suggested that an inaccurate representation of the own body size could still play a role in obesity.

In the present study, we wanted to obtain a more comprehensive picture of a possible body image disturbance in childhood obesity than previously reported. Specifically, we aimed to find out i) whether and in which measures of body representation obese children and adolescents differ from normal-weight mates matched for age and gender and heartbeat detection ii) how the different measures of body representation are associated with each other in both groups. In addition, we followed up obese children and adolescents until discharge from a weight-loss therapy, as we wanted to investigate iii) whether weight loss induced any changes in the body representation of obese children and adolescents. Finally, we also wanted to test iv) whether any of the body representation measures would serve as a predictor for weight loss success in obese children, as suggested by health behavior theories [3, 4].

Materials and Methods

Study design and Participants

The study presented here was conducted as part of the DROMLIN-study (PreDictor Research in Obesity during Medical care—weight Loss in children and adolescents during an INpatient rehabilitation) [25]. The study protocol was approved by the Ethics Committee of the medical faculty for the University Tübingen, Germany. This study is registered at the German Clinical Trials Register (DRKS) with the clinical trial number DRKS00005122.

Children and parents were informed about the study purpose and provided written consent prior to inclusion. In short, 60 overweight and obese children (OBE; age 9–17, 47% male) with a BMI over the 90th percentile for their age and sex specific norms [26] and an indication for hospitalization for weight loss intervention were included. All OBE participated in a weight loss program at the Children Rehabilitation Hospital for Respiratory Diseases, Allergies and Psychosomatics in Wangen i.A., Germany. The program comprised physical activity, cognitive behavioral therapy, and a balanced diet. A detailed description of the setting is reported elsewhere [25]. Exclusion criteria were severe psychological comorbidities, linguistic or intellectual limitations, type-1 diabetes, malignant tumors, systemic disorders, or severe cardiovascular diseases. Additionally, 27 normal weight children (NW; 11–14 years, 56% male) matched for age and gender with a BMI between the 10th to 90th BMI percentile from the surrounding area of the University Hospital Tübingen, Germany were recruited and served as control group.

OBE were tested twice, upon admission (T1) and prior to discharge (T2). The anthropometric and body perception assessments took place in an afternoon session and the heartbeat perception assessment in the morning session. NW were tested once in a single session, and served as control group for T1.

Assessments

Anthropometry. The physical development of the children was assessed using the tanner stages [27, 28]. The tanner scale ranges between 1 (prepubertal) and 4 (mature). In the context of anthropometric measurements, the actual body widths (spine, hip, thigh, upper arm) and body depths (abdomen, buttocks), were measured with a caliper and body circumferences (abdomen, buttocks, thigh, upper arm) with a tape measure, respectively in the morning. Participants were not informed about their body dimensions.

Body size estimation. Two hours after the anthropometry, the same investigator assessed the corresponding body size estimations by instructing the participants to set their dimensions by moving sliders on a 2 m wooden slat. Then, the investigator measured the adjusted dimension without providing any feedback. At the beginning of each trial, the investigator placed both sliders in the middle of the slat. The children's cognitive ability to discriminate between physical dimensions was tested by presenting everyday objects of different size that had to be estimated: a mobile phone (9 cm), a book (24 cm), and a bottle (34 cm). After each presentation, the object was removed and the participant was asked to set its length on the wooden slat.

Tactile size estimation. We conducted a tactile size estimation test similar to the one reported by Keizer et al. [29] at four different body sites (upper spine, upper arm, buttocks, thigh). The participants were blindfolded and the investigator pressed a small caliper/pair of compasses with predefined distances on different body sites. After each tactile stimulation (each distance and body site), the blindfold was removed and the participants had to reproduce the perceived distance using the wooden slat. The distances between the two points were as follows: spine– 20 cm, upper arm– 10 cm, buttocks– 15 cm, thigh– 10 cm.

Perception indices and scores. A perception index for each body size and tactile size estimate was calculated according to the formula: perception index = (estimated / actual body size) x 100 [30]. Next, mean perception scores for each group were calculated as average of the single measures for everyday objects (mobile phone, book, bottle), body width (spine, hip, thigh, upper arm), body depth (abdomen, buttocks), body circumference (abdomen, buttocks, thigh, upper arm) and tactile size estimation (spine, upper arm, buttocks, thigh). Values below 100 indicate an underestimation and values above 100 indicate an overestimation in terms of percent of the actual size.

Heartbeat detection. The heartbeat detection task was performed as reported previously by Pollatos and Schandry [31] in a modified version. During the procedure, a conventional ECG (3991/3-GPP BioLog, UFI Company, Morro Bay, CA) recorded the actual cardiac activity while the child was comfortably seated in a chair and was not allowed to speak and to move. A short test interval of 15 seconds was followed by four intervals of 25, 35, 45 and 55 seconds. Between the intervals were resting periods of 30 seconds. The children were instructed to count during each interval their own heartbeats by concentrating on their heart activity. The procedure was standardized by giving the instructions from a tape. A heartbeat detection index for every interval was calculated by the following formula: 1-(|recorded heartbeats–counted heartbeats|/recorded heartbeats). Next, the mean heartbeat detection score was calculated as average of the heartbeat detection indices of the four intervals 25s, 35s, 45s and 55s. The maximum score is 1, the minimum score is 0. A high index or score indicates a good concordance between the detected and actual heartbeat whereas a low score indicates a poor agreement between the detected and the actual heartbeat.

Concerns about body weight and shape. Eating behavior and concerns about body weight and shape were assessed with the validated Eating Behaviour and Weight Problems Inventory for Children (EWI-C), consisting of 60 items and 10 subscales [32]. In this study, the subscales "figure dissatisfaction" (consisting of 5 items), and "concerns about eating" (consisting of 8 items) are reported. Percentile ranks for the values of the subscales were retrieved by sex and age specific norm tables. Values between the 16^{th} and 84^{th} percentile can be considered as normal.

Statistical analyses

The data were analyzed using SPSS version 19. Normally distributed data are presented as mean±standard deviation. Non-normally distributed data are presented as median [interquartile range] and the perception indices additionally by mean±standard deviation. Differences between OBE T1 and NW were calculated using unpaired t-tests (age, weight, height, BMI-SDS), Chi^2 test (sex) or Mann-Whitney-U-tests if data were not normally distributed (EWI-C, perception indices). Differences between OBE T1 and OBE T2 were analyzed with paired t-test (weight, BMI-SDS) or Wilcoxon signed-rank test if data were not normally distributed (EWI-C, perception indices). We used Spearman correlations to analyze associations between variables, because in all analyzed pairs, at least one variable was not normally distributed. In order to analyze the association between body representation distortion and successful weight loss in OBE, Spearman correlations between the T1 perception scores and the delta BMI-SDS were calculated. The same Spearman correlations were computed using the T1 absolute values of mis-estimation instead of the T1 perception scores. Spearman correlations were computed for correlation analyses between all perception scores and EWI-subscales. In order to control for multiple testing the p-values were false discovery rate (FDR) adjusted [33]. FDR-values of <0.05 and for correlation analyses <0.15 were considered as statistically significant.

Results

Table 1 provides an overview on the characteristics of the study population. At T2, seven children had dropped out so that the longitudinal data refers to a sample of 53 obese children. The length of intervention in OBE was 38±10 (min-max: 16–70) days. To exclude possible age effects, all analyses were repeated excluding the four youngest children (aged 9 to 10 years from the OBE group), which however, did not influence the results. Similarly, we explored whether results would change if absolute values of percentage of mis-estimation instead of perception scores were used. Again, this was not the case.

Group differences OBE T1 versus NW

As displayed in Table 2, both groups overestimated their body widths and body depths while they underestimated their body circumferences. However, the perception indices of body widths, body depths and body circumferences for the different body sites did not differ significantly between OBE and NW. As a result, the corresponding three aggregated perception scores "Body widths", "Body depths" and "Body circumferences" were also similar in OBE versus NW (Fig 1) respectively. Both groups greatly overestimated the distances in the tactile size estimation task (Table 2). However, the perception indices "Spine", "Buttocks" and "Thigh" of this task differed significantly between OBE and NW, with OBE overestimating the distances more than NW (Spine: U(N = 87) = 419.5, FDR = 0.005); Buttocks: U(N = 87) = 498.5, FDR = 0.04; Thigh: U(N = 87) = 342.5, FDR<0.001; Table 2). Consequently, the aggregated perception score "Tactile Size Estimation" also differed between OBE and NW (U(N = 87) = 434.0, FDR = 0.007, d = 0.81; Fig 1). In order to exclude that either changes in mechanoreceptor density through growth or central nervous system maturation influenced tactile size estimation performance, we explored whether performance correlated with the children's height and their tanner stages, which was not the case. The heartbeat detection indices for the different counting intervals were similar in OBE and NW in all intervals (Table 2) and consequently also the aggregated detection accuracy score (Fig 1). The results for the two subscales "Figure dissatisfaction" and "Concerns about eating" are presented in Table 1. In both subscales OBE scored significantly higher than NW ("Concerns about eating": U(N = 87) = 40.00,

Table 1. Characteristics of the study population

				p-value	p-value
	OBE T1 (n = 60)	**OBE T2 (n = 53)**	**NW (n = 27)**	**OBE T1 vs. OBE T2**	**OBE T1 vs. NW**
Sex (♂:♀)	28:32	23:30	15:12	n.a.	n.s.
Age (years)	13.03±1.89	13.04±1.85	12.5±0.9	n.a.	n.s.
[Min-Max]	[9–17]	[9–17]	[11–14]		
Weight (kg)	84.0±20.5	80.9 ± 19.9	45.4 ± 8.2	**<0.001**	**<0.001**
[Min-Max]	[51.0–132.0]	[47–128]	[33.8–63.0]		
Height (cm)	163.1±10.5	163.3±9.9	158.1±9.4	n.s.	n.s.
[Min-Max]	[140–185]	[140–185]	[141–174]		
BMI-SDS	2.51±0.6	2.3±0.6	-0.2±0.6	**<0.001**	**<0.001**
[Min-Max]	[1.1–3.7]	[0.6–3.6]	[-1.3–1.1]		
EWI-C Figure dissatisfaction	83[68–93]	86[72–97]	35[28–42]	n.s.	**<0.001**
EWI-C Concerns about eating	90[78–96]	84[78–90]	25[24–53]	**0.005**	**<0.001**

Characteristics of obese children (OBE) before (T1) and after weight loss (T2) and the normal-weight children (NW) are displayed along with subscales of the validated Eating Behaviour and Weight Problems Inventory for Children (EWI-C [32]). Normally distributed data are presented as mean±standard deviation and non-normally distributed data as median[interquartile range]. Data were compared between OBE T1 versus OBE T2 and OBE T1 versus NW, respectively. P-values <0.05 were considered as statistically significant. Min = Minimum, Max = Maximum, n.a. = not applicable, n.s. = not significant.

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p<0.001, "Figure dissatisfaction": U(N = 87) = 72.00, p<0.001), reflecting higher body dissatisfaction and eating concern in obese children.

Correlations between body representation measures

Correlations between all the perception scores and the subscales of the EWI-C were computed separately for OBE (at T1) and NW (Table 3). In OBE, the perception score "body width" correlated weakly to moderately with the perception scores "body depths", "tactile size estimation and the EWI-C scale "eating concern". The perception score "body depth" correlated weakly with "tactile size estimation". A moderate correlation was observed between the two EWI-C scales "eating concern" and "figure".

In NW, the perception score "body width" correlated moderately with "tactile size estimation". Further, the perception score "body width" correlated with "body depth" and "body circumference", but this finding did not withstand FDR-adjustment. In NW, the two EWI-C scales "eating concern" and "figure" correlated strongly with each other. Neither in OBE nor in NW, correlations between the heartbeat detection score and other perception scores or EWI-C scales were found.

Changes in OBE body representation between T1 and T2

In the OBE group, the weight loss treatment induced neither a significant effect with regard to any of the aggregated perception scores for "Body widths", "Body depths", Body circumferences"

Table 2. Perception indices of body perception in obese children (OBE) before (T1) and after weight loss (T2) in comparison to normal-weight children (NW).

	Mean±SD			Median [IQR]			FDR	FDR
Perception indices	**OBE T1**	**OBE T2**	**NW**	**OBE T1**	**OBE T2**	**NW**	**OBE T1 vs. OBE T2**	**OBE T1 vs. NW**
Body widths								
Spine	105±17	102±17	103±18	105[93–116]	101[90–111]	99[90–113]	0.4576	0.6554
Hip	114±16	114±16	108±19	114[103–124]	111[103–121]	106[96–117]	0.9823	0.1652
Thigh	126±24	130±15	137±43	124[107–140]	130[118–140]	130[109–164]	0.3822	0.471
Upper arm	133±38	135±29	137±28	127[109–155]	131[111–152]	141[123–151	0.6547	0.471
Body depths								
Abdomen	124±27	128±19	126±25	122[108–141]	127[117–142]	130[108–151]	0.6512	0.8016
Buttocks	107±21	110±18	104±21	103[93–120]	107[95–124]	105[90–117]	0.3822	0.9102
Body circumferences								
Abdomen	80±23	77±17	87±19	77[68–88]	76[64–88]	82[72–101]	0.3822	0.302
Buttocks	75±17	70±15	75±17	73[64–90]	69[58–80]	74[64–89]	0.1257	0.9102
Thigh	93±23	95±21	91±26	90[77–113]	96[77–108]	97[69–111]	0.8624	0.9102
Upper arm	92±27	98±22	102±23	92[73–108]	96[82–109]	100[89–113]	0.3822	0.3112
Tactile size estimation								
Spine	178±45	162±31	145±29	170[146–199]	156[144–171]	150[119–166]	0.1257	***0.0049***
Upper arm	180±76	196±63	181±57	170[127–228]	190[140–238]	169[139–206]	0.1257	0.9102
Buttocks	176±49	167±40	149±25	171[143–210]	163[139–197]	140[130–169]	0.6513	***0.0378***
Thigh	194±76	205±64	133±34	184[143–236]	100[159–252]	138[108–155]	0.131	***0.0005***

Perception indices of everyday objects, body widths, body depths, body circumferences, tactile size estimations and heartbeat detection accuracy are presented as mean±standard deviation and as median[interquartile range] due to the non-normal distribution of most data. Except for the heartbeat detection indices, values below 100 indicate an underestimation and values above 100 indicate an overestimation in terms of percent of the actual size. For the heartbeat detection, a score of 1 indicates absolute accuracy of heartbeat detection and the minimum score of 0 indicates that no heartbeat was perceived. The perception indices were compared between OBE T1 versus OBE T2 and OBE T1 versus NW, respectively. Due to multiple testing the p-values were false discovery rate (FDR)-adjusted. FDR values <0.05 were considered as statistically significant.

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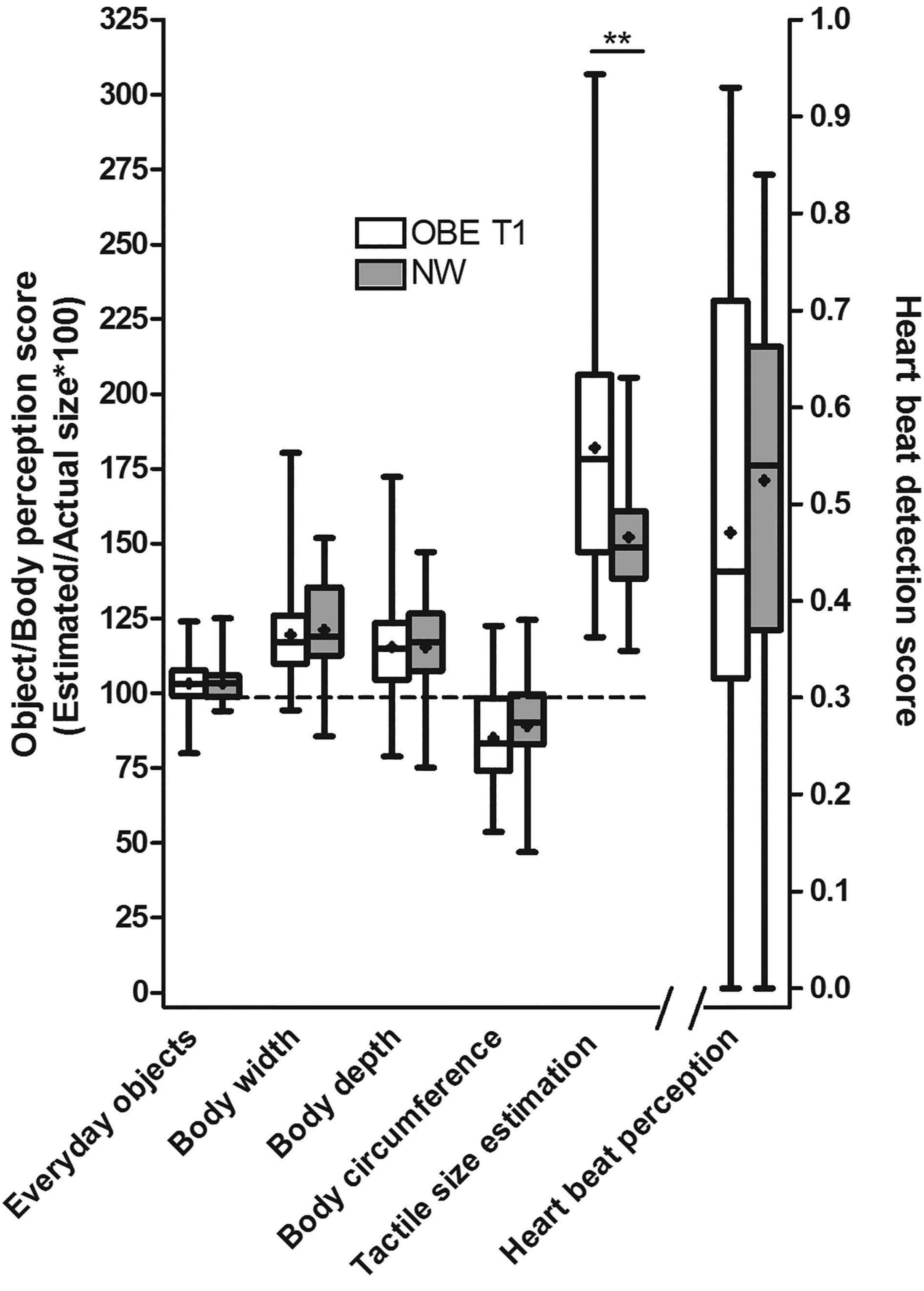
**
OBE T1
NW
Object/Body perception score (Estimated/Actual size*100)
Heart beat detection score
325
300
275
250
225
200
175
150
125
100
75
50
25
0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Everyday objects
Body width
Body depth
Body circumference
Tactile size estimation
Heart beat perception

Fig 1. Perception Scores of body perception in obese children (OBE) before weight loss (T1) in comparison to normal-weight children (NW). The perception scores of everyday objects, body width, body depth, body circumference, tactile size estimation and heartbeat detection are displayed as box-whiskers with a cross, the latter depicting the mean. Except for the heartbeat detection score, values below 100 indicate an underestimation and values above 100 indicate an overestimation in terms of percent of the actual size. For the heartbeat detection, a score of 1 indicates absolute accuracy of heartbeat detection and the minimum score of 0 indicates that no heartbeat was perceived. The mean±standard deviation of the perception scores were as follows: *Everyday objects*–OBE: 103±08, NW: 103±07; *Body width*–OBE: 120±15, NW: 121±17; *Body depth*–OBE 115±20, NW: 115 ±17; *Body circumference*–OBE: 85±16, NW: 89±16; *Tactile size estimation*–OBE: 182±41, NW: 152±25; *Heartbeat detection*–OBE: 0.47±0.26, NW: 0.52±0.20. Due to multiple testing the p-values were false discovery rate (FDR)-adjusted. FDR values <0.05 were considered as statistically significant. ** indicates FDR<0.01.

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nor for the "Tactile Size Estimation" (Fig 2A). We also analyzed the individual changes in aggregated perception scores between T1 and T2 and found no trend of improvement or worsening (Fig 2B). In contrast, the heartbeat detection accuracy improved significantly in the course of weight loss from T1 to T2 in all examined intervals (Table 2) and in the aggregated score (Z(N = 52) = -5.174, FDR<0.001, d = 0.67, Fig 2B). Also, we observed that OBE improved in the EWI-C subscale "Concerns about eating" (Z(N = 53) = -2.81, p = 0.005).

Prediction of weight loss success

None of the assessed measures of body representation at T1 correlated with the weight loss success (delta BMI-SDS).

Discussion

Our observations suggest that obese children and adolescents generally represent their bodies as accurate as normal weight age mates, though in OBE, body size representation was associated with eating concern. Our observation that none of the assessed variables predicted weight loss success is contradictory to ideas that a lack of awareness of their excess body size or poor interoception contributes to being overweight. However, we observed that in the obese children and adolescents, not only eating concern, but also heartbeat detection accuracy improved throughout weight loss, suggesting that the program induced improvements in interoceptive processing.

Table 3. Correlations between perception scores and subscales of the Eating Behaviour and Weight Problems Inventory for Children (EWI-C)[32] in OBE and NW group.

	Body width	Body depth	Body circumference	Tactile size	Heartbeat	EWI-C EC	EWI-C FD
Body width		0.42	-0.40	***0.55*** **	-0.05	-0.02	-0.08
Body depth	***0.41*** **		0.21	0.28	-0.05	0.05	-0.17
Body circumference	0.17	0.09		-0.18	0.17	0.21	0.02
Tactile size estimation	***0.27****	***0.26****	-0.21		-0.14	0.05	0.01
Heartbeat detection accuracy	-0.05	0.12	-0.09	-0.11		0.02	0.2
EWI-C Eating Concern	***0.31****	0.03	***0.29****	0.09	-0.19		***0.75*** **
EWI-C Figure Dissatisfaction	-0.1	-0.17	0.04	-0.21	-0.25	***0.43*** **	

Spearman correlations were computed and the correlation coefficients rho are presented for obese children (OBE, white background) and normal-weight children (NW, grey background). The p-values were false discovery rate (FDR) adjusted for multiple testing. A FDR <0.15 was considered as statistically significant.

* indicates FDR <0.15 but ≥0.05

** indicates FDR<0.05.

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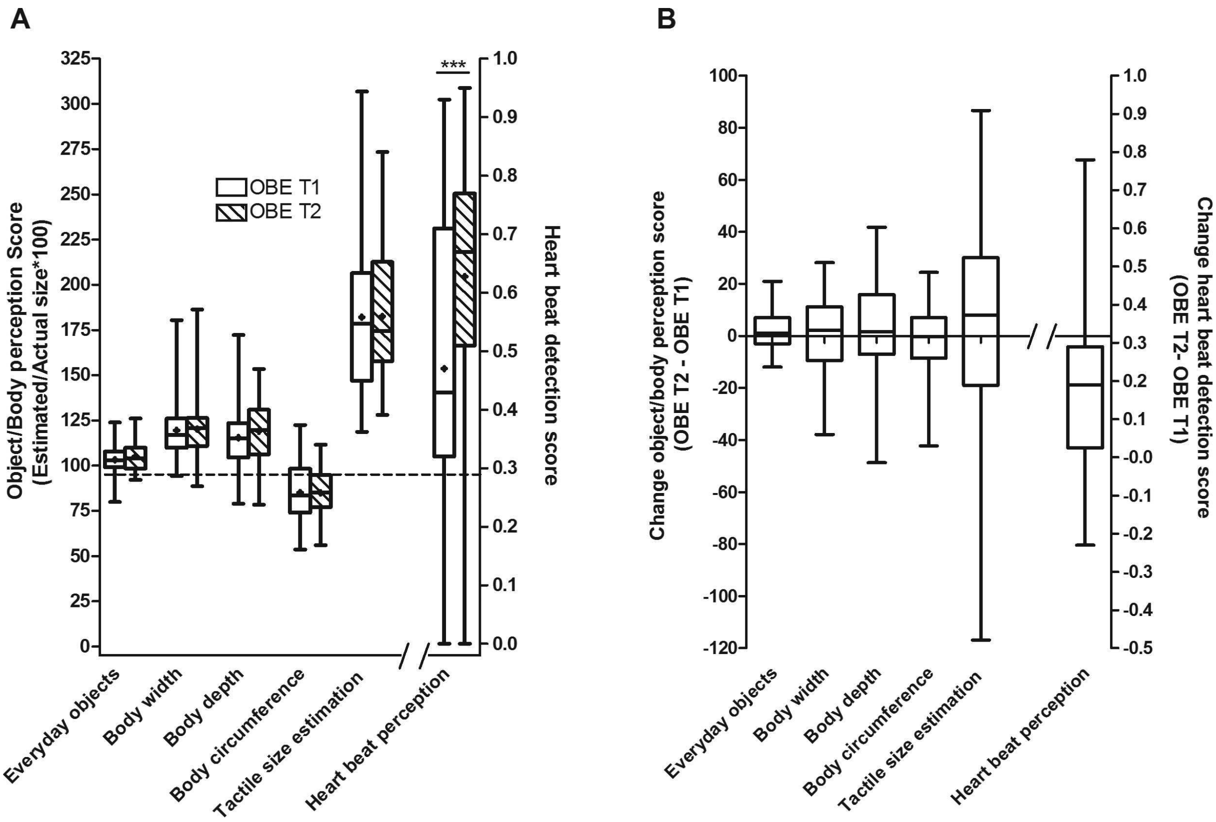

Fig 2. Perception Scores of body perception in obese children (OBE) before (T1) and after weight loss (T2). A: The perception scores of everyday objects, body width, body depth, body circumference, tactile size estimation and heartbeat detection are displayed as box-whiskers with a cross, the latter depicting the mean. Except for the heartbeat detection score, values below 100 indicate an underestimation and values above 100 indicate an overestimation in terms of percent of the actual size. For the heartbeat detection, a score of 1 indicates absolute accuracy of heartbeat detection and the minimum score of 0 indicates that no heartbeat was perceived. The mean±standard deviation of the perception scores were as follows: *Everyday objects*–T1: 103±08, T2: 105±08; *Body width*–T1: 120±15, T2: 120±14; *Body depth*–T1: 115±20, T2: 119±16; *Body circumference*–T1: 85±16, T2: 85±12; *Tactile size estimation*–T1: 182±41, T2: 183±35; *Heartbeat detection*–T1: 0.47±0.26, T2: 0.63±0.21. Due to multiple testing the p-values were false discovery rate (FDR)-adjusted. FDR values <0.05 were considered as statistically significant. *** indicates FDR<0.001. **B:** The change values of the perception scores in OBE are presented as box-whiskers.

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We observed no uniform group differences between OBE and NW with regard to their general body size perception and heartbeat detection accuracy, but only in tactile size estimation and body dissatisfaction. In the body size estimation task, our observations do not confirm previous results from figure rating tasks suggesting that obese children underestimate their size [13, 14, 34]. Rather, our observations match findings obtained with depictive methods in adults by [15] that showed no difference between obese and normal-weight participants. The discrepancy may be due to the fact that figure rating tasks assess own body size perception as compared to a certain social range, whereas metric body size estimation, as used in this this study, assesses body size estimation for the actual size. Several studies have already shown that families and peers of obese children often do not perceive the child as obese, which may be beneficial for the child's quality of life [35–37]. It is likely that obese children do not see themselves as different from their peers as they are, and thus underestimate in figure rating tasks while they might be accurate in tasks that do not require a social comparison.

Our observation that OBE children were less accurate than NW children in tactile size estimation, is in line with previous findings in adults [24]. Interestingly, differing from these previous studies, we found that both groups overestimated, but OBE children did so to a significantly higher degree. Tactile size estimation performance did neither correlate with height nor with tanner stages of physical development. We therefore consider it unlikely that differences in growth and maturation processes might have caused the group differences, as previous studies suggested [38, 39]. Rather, our results are similar to those found in anorexia nervosa suggesting that tactile size, despite being considered to assess implicit body representation, might be influenced top-down, e.g. by body dissatisfaction [24]. Hence, it might be the case that the overestimation of OBE children reflects their perception of being large although correlations between body dissatisfaction and tactile size estimation did not yield significance.

Heartbeat detection accuracy is assumed to be the central construct underpinning other interoceptive measures [40]. Further, it has been observed to be negatively correlated with the tendency to evaluate one's body based on appearance rather than for its effectiveness [41]. Our observation of no group differences in heartbeat detection accuracy contradicts previous claims that a diminished perception of the inner status of the body might contribute to overweight [20]. Interestingly, in a large sample of children ($n>1500$) aged 6 to 11 years, no differences were observed between overweight and normal-weight children at a first assessment, whereas differences between the groups were evident one year later [9]. Our observations suggest that diminished heartbeat perception is likely not a general symptom of obesity. However, heartbeat perception is involved in weight regulation, possibly as a mediator for body-related cognitions.

Finally, our observation of high body dissatisfaction in OBE children confirm Wardle and Cooke [1],who identified high body dissatisfaction in OBE children as one of the main factors of their compromised psychological well-being. At the same time, our observation suggests that it is not the case that obese children have a lack of awareness of the problem but that they are aware of and suffering from their excess weight.

Group wise correlation analyses of the different measures of body representation revealed an interesting pattern: Whereas in the NW group questionnaire measures of eating concern and body dissatisfaction were independent from other body representations, high eating concern was associated with body size overestimation in the OBE group. This indicates that in obese children and adolescents, cognitions of being too fat are possibly internalized to a higher degree than previously assumed and thereby might influence body size estimation on a very basic level.

Interestingly, we found that different measures of body representation do not homogeneously correlate with each other. In both the OBE and the NW group, measures related to size estimations were correlated moderately with each other, but not with heartbeat detection accuracy. This supports the notion of body representation as conglomerate of multiple rather independent representations and emphasizes the necessity of a multi-method account.

Our third research question asked for the role of body representation in weight loss treatment. Although, heartbeat detection accuracy is unlikely to be involved in the etiology of overweight, our observation of improved heartbeat detection accuracy at T2 indicates that weight loss treatment affects interoception. From our data, it is unclear whether heartbeat perception accuracy is rather a marker or even a potential moderator variable for weight loss. A possible mechanism of this relationship includes physical fitness, which has been observed to be associated with heartbeat detection accuracy in high BMI children [21]. Alternatively, it could reflect changes in body image, as weight loss might reduce tendencies to evaluate oneself based on appearance [41]. However, the causal structure of this association is yet unknown.

In line with other studies, we also observed that body dissatisfaction, as reflected by the scale "eating concern" improved throughout the weight loss treatment [17, 18, 42, 43]. It has to be noted that body dissatisfaction remained on a level higher than in the NW group even at the end of the program. However, this suggests that positive effects on psychological well-being apply as soon as weight loss starts.

With regard to the predictive power of body representation for weight loss success, we found that none of the investigated measures predicted weight loss success of OBE children. Opposed to widely used models of health behavior change, our results suggest that a lack of awareness and, consequently, motivation for weight loss, is not the main hurdle for weight loss in obesity [3, 7, 44]. However, we observed body dissatisfaction to be very sensitive to weight loss, suggesting that motivational variables might be relevant for therapy adherence and success.

It is a limiting factor of this study i) that we were not able to analyze body representation in longer follow-up intervals and ii) that our design does not allow us to disentangle whether the observed changes in body dissatisfaction and interoception were rather consequences or even actively contributing to weight regulation. Although we have not found an immediate link between weight and body representation, it is still possible that some of the body representations investigated here are associated with weight loss, weight loss maintenance or weight gain in a long-term perspective. Studies with a longer follow-up interval and more measurement time intervals could help to clarify this question and to learn more about the mechanisms through which body representation and weight regulation interact.

There are also several strengths to our study. To our knowledge, we are the first to examine body representation of obese children from a multi-modal perspective and in both a cross sectional and a longitudinal setting. That way, we were not only able to compare body representation of obese children to normal weight children, but could also identify changes that occur in the course of weight loss. We observed that obese children do not have general problems to represent their excess body size. However, correlation analyses indicate that their self-categorization as "too large" is likely influencing their body representation on a basal level. Further studies focusing on the association between perception and representation of the body might help to better explain this observation.

For clinical practice, it is important that we observed counter-evidence for the idea that obese children lack awareness of their excess size or motivation to lose weight. Still, we observed that interoceptive awareness, as indicated by heartbeat detection accuracy, changes throughout weight loss therapy, suggesting that it might play a role in weight regulation. Further research is needed that tracks different types of body representation throughout development and long-term treatment of overweight. Specifically, the role of interoceptive awareness for weight loss treatment needs further exploration. Our findings also show that neither high body dissatisfaction nor accurate awareness of the own excess size translate into higher weight loss success. However, to improve psychosocial well-being of overweight children, weight loss interventions that specifically target body image may be useful.

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Author Contributions

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Formal analysis: IM.

Funding acquisition: IM PE.

Investigation: HS.

Methodology: IM PE HS.

Project administration: HS IM.

Supervision: IM PE DD.

Visualization: IM SCM.

Writing – original draft: SCM IM.

Writing – review & editing: KEG DD SZ MT FJ PE HS.

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ORIGINAL ARTICLE

Assessing body image in anorexia nervosa using biometric self-avatars in virtual reality: Attitudinal components rather than visual body size estimation are distorted

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Background. Body image disturbance (BID) is a core symptom of anorexia nervosa (AN), but as yet distinctive features of BID are unknown. The present study aimed at disentangling perceptual and attitudinal components of BID in AN.

Methods. We investigated $n = 24$ women with AN and $n = 24$ controls. Based on a three-dimensional (3D) body scan, we created realistic virtual 3D bodies (avatars) for each participant that were varied through a range of ±20% of the participants' weights. Avatars were presented in a virtual reality mirror scenario. Using different psychophysical tasks, participants identified and adjusted their actual and their desired body weight. To test for general perceptual biases in estimating body weight, a second experiment investigated perception of weight and shape matched avatars with another identity.

Results. Women with AN and controls underestimated their weight, with a trend that women with AN underestimated more. The average desired body of controls had normal weight while the average desired weight of women with AN corresponded to extreme AN (DSM-5). Correlation analyses revealed that desired body weight, but not accuracy of weight estimation, was associated with eating disorder symptoms. In the second experiment, both groups estimated accurately while the most attractive body was similar to Experiment 1.

Conclusions. Our results contradict the widespread assumption that patients with AN overestimate their body weight due to visual distortions. Rather, they illustrate that BID might be driven by distorted attitudes with regard to the desired body. Clinical interventions should aim at helping patients with AN to change their desired weight.

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Key words: Anorexia nervosa, body image disturbance, body size estimation, eating disorders.

Anorexia nervosa (AN) is a serious eating disorder that goes along with high rates of psychological and physical comorbidity as well as with increased levels of disability and mortality (Zipfel *et al.* 2015; Fichter & Quadflieg, 2016). Treatment of AN is expensive and often yields sub-clinical symptoms rather than complete remission (Egger *et al.* 2016; Schmidt *et al.* 2016). In addition to self-induced underweight and circumvention or even fear of gaining weight, body image disturbance (BID) is a core symptom of AN (American Psychiatric Association, 2013). As yet, distinctive features and mechanisms of BID remain unclear, specifically in regards to the contributions of sensory perceptual distortions *v.* cognitive–affective disturbance (Dakanalis *et al.* 2016; e.g. Frank & Treasure, 2016). To improve the clinical treatment of AN, a deeper understanding of BID in AN is needed.

There is consistent evidence that cognitive–affective components of body image are disturbed in AN. Several studies found that patients with AN report higher body dissatisfaction, weight and shape concerns, higher drive for thinness and a thinner desired weight than control participants (Cash & Deagle, 1997; Zipfel *et al.* 2014; Moscone *et al.* 2017). Other studies observed that patients with AN are satisfied with their weight (Striegel-Moore *et al.* 2004;

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Benninghoven *et al.* 2007), which given their underweight is interpreted to reflect a disturbed body image, as well. It has been repeatedly suggested that sensory perceptual distortions might underlie these findings in the sense that patients with anorexia nervosa (AN) 'see' their bodies fatter than they really are or that they do not recognize weight loss (Bruch, 1962; Slade & Russell, 1973; Farrell *et al.* 2005).

Indeed, several studies observed that patients with AN overestimate their body size in different visual size estimation tasks (Mölbert *et al.* n.d.; Cash & Deagle, 1997; Farrell *et al.* 2005; Gardner & Brown, 2014) and even in non-visual measures (Gaudio *et al.* 2014). However, the interpretation of the overestimation effect as indicative for perceptual distortion has been questioned: The magnitude of overestimation has been found to be sensitive to the instruction wording such that a focus on 'knowledge' *v.* 'feelings' often reduced or even revoked the overestimation (Proctor & Morley, 1986; Bowden *et al.* 1989; Caspi *et al.* 2017). Additionally, it has been suggested that demand characteristics influenced performance, as patients with AN might have thought they were asked to illustrate their experience of being 'too fat' (Smeets, 1997). This explanation is supported by psychophysics studies that did not replicate overestimation (Gardner & Moncrieff, 1988; Gardner & Bokenkamp, 1996; Smeets *et al.* 2009).

An alternative explanation suggests that overestimation might be a secondary effect of the low weight of individuals with AN, as a contraction bias could distort their estimates toward the average body weight (Cornelissen *et al.* 2013, 2015). This explanation, however, implies that patients with AN should also overestimate the weight of other thin people. Interestingly, some recent studies observed that patients with AN indeed tend to overestimate other people's weight when rating their weight in categories (Horndasch *et al.* 2015; Moody *et al.* 2016). In contrast, another study observed that participants with AN accurately memorized and adjusted another person's body (Øverås *et al.* 2014). Hence, it is still unclear under which circumstances patients with AN overestimate weight and how this overestimation is characterized.

In this study, we made use of recent technical advances to assess the contributions of both cognitive–affective and perceptual processes to the body weight estimation in AN. Specifically, we used a stereoscopic virtual reality life-size stereo display, a three-dimensional (3D) body scanner and a statistical body model that allow for realistic weight manipulations of photo-realistic virtual avatars and naturalistic mirror-scenario presentation of these avatars. Importantly, this technology also enabled us to create artificial other persons that had the participant's body shape and weight. To reduce demand characteristics, we used psychophysical tasks and an outside-treatment-setting, and investigated the following questions: (1) Do women with AN overestimate their weight or do they differ in their sensitivity to weight change as compared to controls? (2) How do women with AN differ from controls with regard to their desired body? (3) Are estimated own body size or desired body size correlated with eating disorder symptoms or own body weight? Further, to investigate the influence of a low body weight on perception of other persons' weight in AN, we conducted a second experiment asking. (4) Do size estimates and most attractive body weight change when they refer no longer to the own body but to another person who is matched in body shape and weight? Finally, we also invited participants back for a replication of Experiment 1 in 2D to find out (5) How robust are our findings on own body size estimation and desired body size?

Methods

Participants

$n = 24$ women with AN diagnosed according to DSM-5 and $n = 24$ age and gender matched normal weight control participants with no history of mental disorders gave their informed written consent and participated in the study. Exclusion criteria for all participants were current pregnancy or lactation, diseases of the central nervous system, alcohol- or drug dependence, schizophrenia, bipolar disorder, and acute suicidal tendency. Women with AN were recruited from the inpatient ($n = 23$) and outpatient ($n = 1$) service of the Department of Psychosomatic Medicine and Psychotherapy at the University Hospital Tübingen. The experimenter was not part of the therapeutic team, and women with AN were informed that data assessed in the study would not be shared with the therapeutic team. At study inclusion, patients in inpatient treatment were treated for Md = 4 weeks (Min = 1 week, Max = 16 weeks). The study was approved by the local ethics committee of the University Tübingen and the Medical Faculty Tübingen.

Stimulus generation and technical setup

For each participant, we generated two individual avatars: For Experiments 1 and 3, a 3D photo-realistic self-avatar that could be morphed in a range of ±20% weight and for Experiment 2, a 3D avatar that was matched in weight and body shape, could also be morphed in the range of ±20% weight, but had another identity (Fig. 1*a*). To record the participant's body

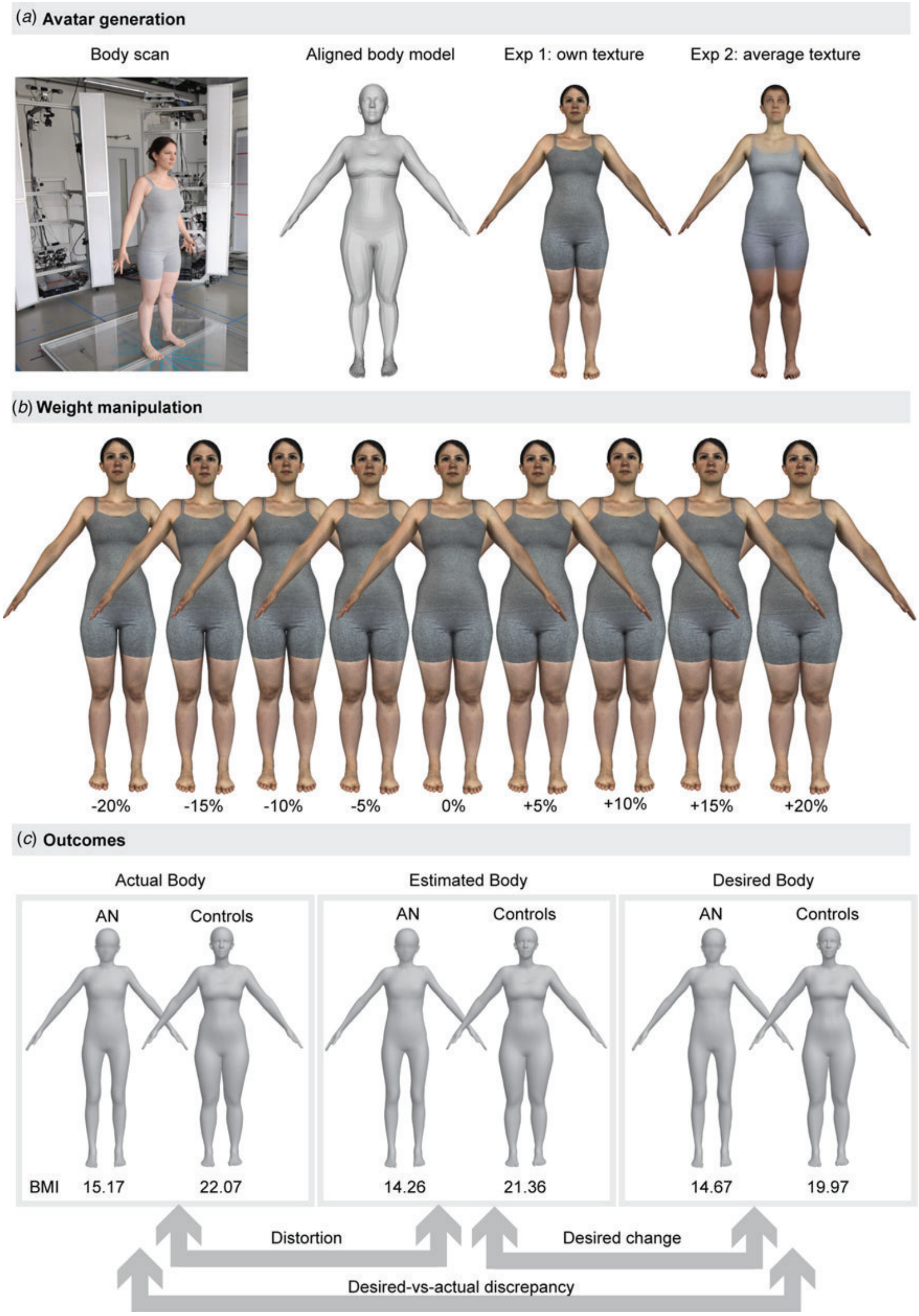

Fig. 1. (*a*) Avatar generation based on a 3D body scan for Experiment 1 (own photo-realistic texture) and Experiment 2 (average texture). (*b*) Illustration of weight manipulations. (*c*). Illustration of outcome parameters, average actual and average adjusted body mass index (BMI; kg/m^2) in Experiment 1 (Method of Adjustment task). The depicted persons provided written consent to be shown in publications.

shape and to generate the individual photo-realistic appearance (texture), we used a full-body scanning system (3dMD, Atlanta/GA). The body shape data was afterwards registered to a parametric model of body shape (Anguelov *et al.* 2005; Hirshberg *et al.* 2012). For each participant, the individual parametrized body shape was then distorted based on weight-associated shape deformations found in the 2094 women from the CAESAR dataset of body scans (Robinette *et al.* 1999) to reflect weight changes of ±20% (Fig. 1*b*). The weight and shape matched avatars for Experiment 2 were generated by keeping the individual avatar's original geometry (same height, weight and exact body shape) while replacing its texture with a standard appearance [predefined eye and hair color, clothes, etc., cf. Piryankova *et al.* (2014)].

In Experiments 1 and 2, avatars were presented on an immersive life-size stereoscopic display that mimicked in virtual reality the situation of looking at oneself in a mirror. In Experiment 3, avatars were presented in 2D on an ordinary desktop monitor. A detailed description of the stimulus generation and technical setup is provided in the supplement.

Procedure

The procedure comprised: (1) A diagnostic session (1–2 h), (2) the 3D body scan (20 min), (3) an experimental session with Experiments 1 and 2 (1 h) and optionally (4) Experiment 3, a desktop replication of Experiment 1 at least 1 week later (30 min). Session 1–3 took place within 3–17 days. In the diagnostic session, the eating disorder examination interview on eating behavior, attitudes toward weight and shape (EDE; Cooper & Fairburn, 1987; Hilbert & Tuschen-Caffier, 2010), and the SCID-I interview parts on affective disorders, substance abuse, anxiety disorders, and somatoform disorders (Wittchen *et al.* 1997) were conducted. Further, questionnaires were administered to assess self-esteem (Rosenberg SES; Rosenberg, 1965; Ferring & Filipp, 1996; von Collani & Herzberg, 2003), body image (FKB-20; Clement & Löwe, 1996; EDI-2 scales 'Drive for Thinness' and 'Body Dissatisfaction'; Paul & Thiel, 2005) and social comparison tendencies (PACS; Mölbert *et al.* 2017).

At the beginning of the experimental session, each participant was informed that based on her body scan, an exact model and more or less manipulated models of her body had been generated. Manipulations were explained using a balloon analogy stating that an algorithm had manipulated the participant's body as if one would blow up or shrink a balloon. The participant was told that she would now see different versions of her body and had to decide whether the version was exactly her body or a manipulated version. In Experiment 1, participants estimated the size of their own body with photo-realistic texture and indicated their desired body size. In Experiment 2, participants estimated the size of the weight and shape matched avatar that they memorized before. All instructions were then modified to refer to the memorized avatar. Experiment 3 followed the procedure of Experiment 1.

Each experiment consisted of three tasks: In the One-Alternative-Forced-Choice (1AFC) task, participants randomly saw bodies at ±0, 5, 10, 15, and 20% of their weight each 20 times for 2 s and afterwards had to indicate whether they agreed to the statement 'This is my body' or not (in case they thought it was a manipulated version). In Experiment 2, the statement was modified to 'This is the correct body'. In the Method of Adjustment (MoA) tasks, participants could continuously adjust the avatar in steps of 0.05% of participant's body mass index (BMI) within the ±20% weight range, and were instructed to adjust it nine times to their current and nine times to their ideal weight. Each of the nine avatars from the 1AFC task was used as a starting avatar once. In Experiment 2, the instructions referred to the remembered or the most attractive body. The order of the experiments and tasks were kept constant to keep participants as naïve as possible for Experiment 1. Before and after the experimental session, participants filled out the state-trait-anxiety questionnaire in its state form (Laux *et al.* 1981). Further, after the session, participants completed a post-questionnaire asking to rate on a Likert scale from 1 (not at all) to 7 (very much) how similar they perceived the two avatars (overall impression) to themselves and whether they identified with their avatar. Piryankova *et al.* (2014) observed such ratings to be sensitive to dissimilarities between avatar and participant. A more detailed description of the experimental procedure is provided in the supplement.

Results

Sample

Sample characteristics are summarized in Table 1. Participants with AN and controls did not differ with respect to age, but in terms of height, weight, BMI, body dissatisfaction, self-esteem, comparison habits with regard to outer appearance and eating disorder symptoms (Table 1). 30% of women with AN fulfilled DSM-5 criteria for comorbid major depression. Women with AN reported that they had received the diagnosis of AN for the first time Md = 3 years ago (Min = 0 years, Max = 23 years). According to DSM-5 severity classification, 21/24 (87.5%) women with AN had extreme

Table 1. *Sample characteristics and group comparisons (t tests and effect size d) for age, body mass index, interview and questionnaire data*

	Women with AN					Controls						
	M	S.D.	Md	Min	Max	M	S.D.	Md	Min	Max	Sig.	*d*
Age	24.00	6.35	21.00	19.00	39.00	24.13	6.42	21.00	18.00	41.00	N.S.	0.01
BMI (kg/m^2)	15.17	1.47	14.97	12.68	17.96	22.07	1.85	21.50	19.41	25.51	***	2.08
EDE Total	2.23	1.05	2.43	0.51	4.38	0.33	0.28	0.29	0.00	0.96	***	1.42
EDE Res	2.53	1.40	2.80	0.00	4.60	0.34	0.62	0.00	0.00	2.20	***	1.08
EDE EC	1.45	1.07	1.40	0.00	3.80	0.04	0.10	0.00	0.00	0.40	***	1.20
EDE WC	2.42	1.41	2.00	0.40	6.00	0.46	0.56	0.30	0.00	2.20	***	1.00
EDE SC	2.52	1.30	2.00	0.63	5.13	0.49	0.29	0.50	0.00	1.00	***	1.27
EDI-2- DT	29.04	8.11	31.50	9.00	40.00	12.92	6.44	10.50	7.00	32.00	***	1.11
EDI-2-BD	35.50	8.93	37.00	14.00	54.00	23.75	8.99	25.00	9.00	50.00	***	0.66
BIQ-VBD	27.56	6.01	30.00	15.00	39.00	37.38	5.32	37.50	27.00	45.00	***	0.87
BIQ-NBE	33.58	8.66	33.50	17.00	50.00	17.71	5.23	16.00	11.00	38.00	***	1.14
RSE	13.08	7.00	12.50	3.00	27.00	24.17	4.67	24.50	11.00	30.00	***	0.95
PACS	17.50	3.15	17.00	12.00	25.00	11.88	3.98	12.00	5.00	23.00	***	0.78
STAI pre	47.67	10.33	47.00	30.00	70.00	31.83	6.07	31.50	21.00	49.00	***	0.97
STAI Diff.	−1.77	10.22	−2.00	−19.00	31.00	−0.17	4.69	−2.00	−5.00	17.00	N.S.	0.11

***$p < 001$ after Bonferroni-correction.

BMI, body mass index; EDE, eating disorder examination interview (Cooper & Fairburn, 1987; Hilbert & Tuschen-Caffier, 2010); EDE Total, EDE total score; EDE Res, subscale restraint, EDE EC, subscale eating concerns; EDE WC, subscale weight concerns; EDE SC, subscale shape concerns; EDI-2, Eating Disorder Inventory – 2 (Paul & Thiel, 2005); EDI-2-DT, subscale Drive for Thinness; EDI-2-BD, Subscale Body Dissatisfaction; BIQ, Body Image Questionnaire FKB-20 (Clement & Löwe, 1996); BIQ-VBE, subscale vital body dynamics; BIQ-NBE, subscale negative body evaluation; RSE, Rosenberg Self Esteem Scale (Ferring & Filipp, 1996; von Collani & Herzberg, 2003); PACS, Physical Appearance Comparison Scale (Thompson *et al.* 1991; Mölbert *et al.* 2017); STAI, State Trait Anxiety Inventory; State-Form (Laux *et al.* 1981); STAI pre, before experiment; STAI Diff, change after experiment.

AN in the past, 2/24 (8.3%) had severe AN in the past and one (4.1%) had moderate AN in the past. At study intake, AN was classified as extreme in 13/24 (54.1%), as severe in 3/24 (12.5%), as moderate in 5/24 (20.8%) and as mild in 3/24 (12.5%) of women with AN. Women with AN had higher levels of anxiety before the experimental session (3) but reduced their anxiety throughout the session as much as controls did (Table 1). Due to organizational and technical issues, missing data occurred in most of the assessed variables and outcome parameters, but it was randomly distributed and affected only 2.7% of all values over the whole sample from analyzed data, so that we opted against imputation.

Manipulation check

In the post-questionnaire, 75% of participants in each group stated that they felt the avatar represented themselves in virtual reality. All participants stated that they experienced the avatar with own appearance in Experiment 1 as more similar to themselves than the weight and shape matched avatar with another identity in Experiment 2 [women with AN: mean *self* = 5.59 (S.D. = 0.96), *other* = 4.18 (1.62); Controls: *self* = 6.25 (1.03), *other* = 4.88 (1.57); $F_{(1,44)} = 30.36$, $p < 0.001$]. Women with AN, however, generally rated the avatars as less similar to themselves than controls [$F_{(1,44)} = 5.01$, $p < 0.05$].

Experiment 1: Perception of own body weight

Figure 1*c* and Table 2 provide an overview on the experimental outcome parameters for both groups. Details on the parameter calculation and the statistical analysis are provided in the supplement. *T* tests were used to test whether the parameters significantly differed from zero; group differences were analyzed with univariate analyses of variance (ANOVAs). The outcome parameter *distortion*, reflecting the over- or underestimation in terms of percent of individual actual body weight, was negative and significantly different from zero in both groups and tasks, indicating that both groups consistently underestimated their actual body size in both the 1AFC task and the MoA task (Fig. 2). According to the *distortion* parameter derived from the 1AFC task, women with AN underestimated their weight even more than women in the

Table 2. *Means (M), Standard Deviations (S.D.) and group comparisons (F Test and effect size Eta^2) for outcome parameters of Experiment 1*

	Women with AN ($n = 23$)		Controls ($n = 24$)		sig	η^2
	M	S.D.	M	S.D.		
Distortion 1AFC	−7.38	4.71	−3.80	5.02	*	0.12
Distortion MoA	−5.94	5.81	−3.19	4.89	†	0.06
Sensitivity to weight loss[a]	1.14	0.86	1.54	0.79	N.S.	0.06
Sensitivity to weight gain[a]	1.76	0.46	1.77	0.64	N.S.	0.00
Desired change (MoA)	+2.85	8.28	−6.05	4.33	***	0.32
Desired-*v*.-actual discrepancy	−2.11	8.12	−9.08	6.13	**	0.20

†$p < 0.10$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. Only ** and *** would survive correction for multiple testing. All parameters except for Desired change and Desired-*v*.-actual discrepancy in the AN group were significantly different from zero with $p < 0.001$ (one-sample *t* test). Distortion: discrepancy between estimated current and actual body in percent of actual weight, Sensitivity to weight loss: ln-transformed beta values of Weibull fitted 1AFC data left from peak, Sensitivity to weight gain: ln-transformed beta values of Weibull fitted 1AFC data right from peak. Lower beta values reflect lower sensitivity, i.e. a greater tendency to accept the weight manipulated avatars as equal to the actual weight. Desired change: Difference between desired and estimated weight in percent of actual weight. Desired-*v*.-actual discrepancy: Discrepancy between desired body and actual body in percent weight.

[a] Sample size $n = 21$ AN/$n = 23$ Controls.

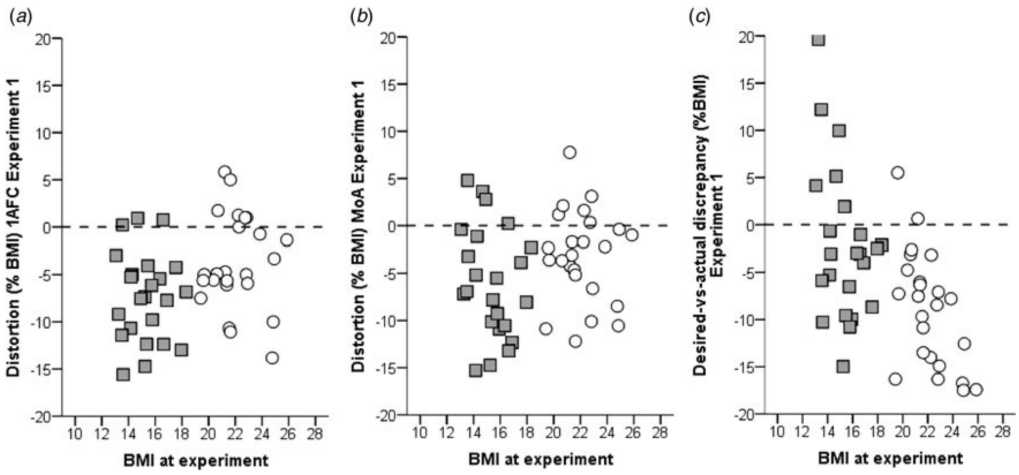

Fig. 2. Distortion as measured by the One-Alternative-Forced-Choice task (*a*) and the Method-of-Adjustment task (*b*) and Desired-*v*.-actual Discrepancy (*c*) in percent of participants' actual weight in Experiment 1 (own photo-realistic texture) depending on personal BMI of the participants. Gray squares: Women with AN. White circles: Controls. The dashed horizontal line indicates hypothetical accurate performance/no desire for weight change. Positive values reflect overestimation/a higher desired than actual body weight, negative values reflect underestimation/a lower desired than actual weight.

control group [$F_{(1,45)} = 6.35$, $p < 0.05$]. However, for the distortion parameter derived from the MoA task there was only a trend towards a group difference [$F_{(1,45)} = 3.09$, $p = 0.086$].

Sensitivity to weight changes was parametrized in the beta-values from fitting cumulative Weibull functions to the left and right side of the peak of the 1AFC answer distributions (Wichmann & Hill, 2001). High beta values reflect steep slopes and therefore high sensitivity to weight changes. *Sensitivity* was lower for changes in the direction of weight loss than for changes in the direction of weight gain relative to own estimated body weight [$F_{(1,42)} = 6.77$, $p < 0.05$], indicating that participants were more willing to accept a thinner body as their own than a fatter body. Importantly, *sensitivity* did not differ between women with AN and controls: Neither the main effect of group [$F_{(1,42)} = 2.01$, $p = 0.13$] nor the interaction side by group [$F_{(1,42)} = 1.52$, $p = 0.22$] was significant.

Desired change of weight, defined as percent weight difference between the estimated and desired body, was significantly different from zero only in the control group (Table 2). Interestingly, 14 women with AN (61%) but only one (4%) control indicated they wanted to gain weight. Consequently, the average *desired change* differed significantly between groups [$F_{(1,45)} =$ 21.63, $p < 0.001$]. Of note, in twelve of the 14 women with AN indicating they wanted to gain weight, this was in the range of 1–10% of their estimated (and in fact significantly underestimated) weight.

Desired-v.-actual discrepancy, reflecting the discrepancy between desired and actual body, was negative and significantly different from zero only in the control group (Table 2). Although 14 women with AN desired to gain weight, only six (26%) actually adjusted their avatar to a weight that was higher than their actual current weight (Fig. 2). On average, the desired body was weighing less than the actual body in both groups, although even more so in the control group [$F_{(1,45)} =$ 11.10, $p < 01$]. The average desired body of the control group still had a BMI of 19.97 and thus was in normal weight range, while the average desired body of women with AN had a BMI of 14.67, which would correspond to extreme AN in DSM-5 (Fig. 1).

The group wise correlations between experimental parameters for the self-texture condition, BMI and questionnaires are provided in Table 3. The correlation analysis revealed that the only consistent pattern emerged between body dissatisfaction-related parameters, as reflected by the correlations of *desired change* and *desired-v.-actual discrepancy* with BMI, questionnaire measures of body dissatisfaction, restrictive eating, self-esteem and the amount of body-related comparisons. This pattern was more consistent in the control group than in the women with AN. We further observed correlations with questionnaire and EDE interview scores for *distortion* (*MoA*) and *sensitivity* to weight loss, but they were not consistent and only present in the control group. None of the correlations survived Bonferroni correction for multiple testing.

Experiment 2: Perception of a weight and shape matched other person

In Experiment 2, we again used *t* tests to test whether the outcome parameters significantly differed from zero. To test differences between groups and to compare the parameters to Experiment 1, we used mixed ANOVAs with group as a between-subject factor and experiment (1/2) as a within-subject factor. All participants accurately identified the previously memorized body: *Distortion* parameters were not significantly different from zero in any of the tasks and groups [AN: mean 1AFC = −1.48 (S.D. = 3.59), $t(21) = -1.93$, $p = 0.07$, MoA = 0.88 (3.63), $t(20) = 1.11$, $p = 0.28$.; Controls: 1AFC = −0.31 (2.88), $t(23) = -0.53$, $p = 0.60$ MoA = −0.98 (2.76), $t(23) = -1.73$, $p = 0.10$]. Overall, *distortion* parameters were smaller in Experiment 2 than in Experiment 1 [1AFC: $F_{(1,41)} = 26.64$, $p < 0.001$; MoA: $F_{(1,41)} = 35.21$, $p < 0.001$], suggesting that the underestimation observed in Experiment 1 was unlikely due to general perceptual distortions.

Sensitivity to weight change was no longer dependent on the direction of change (weight loss *v.* weight gain) [$F_{(1,40)} = 1.53$, $p = 0.22$]. *Post-hoc t* tests illustrated that this was due to the fact that sensitivity to weight loss was smaller than sensitivity to weight gain as opposed to Experiment 1, indicating a trend in both groups to accept fatter bodies as the correct one [AN: mean *beta_left_ln* = 1.74 (S.D. = 0.58), *beta_right_ln* = 1.59 (0.86); Controls: *beta_left_ln* = 1.97 (0.62), *beta_right_ln* = 1.71 (0.62)].

Similar as in Experiment 1, *desired change* of weight and *desired-v.-actual discrepancy* did not differ significantly from zero in women with AN. As the avatar was matched to the participants' own weight, this indicates that women with AN found their own current weight most attractive. Again, controls significantly favored a weight loss [AN: mean *DesiredChange* = −2.09 (S.D. = 6.37), $t(20) = -1.51$, $p = 0.15$, *D-v.-A-Discrepancy* = −1.24 (7.48), $t(20) = -0.75$, $p = 0.46$; Controls: *DesiredChange* = −7.16 (5.57), $t(23) = -6.31$, $p < 0.001$, *D-v.-A-Discrepancy* = −8.14 (6.07), $t(23) = -6.56$, $p < 0.001$]. The ANOVAs revealed a significant difference to Experiment 1 for *desired change* such that women with AN adjusted a lower attractive weight now [$F_{(1,40)} = 15.00$, $p < 0.001$] and a trend for *desired-v.-actual-discrepancy* to be smaller [$F_{(1,40)} = 3.57$, $p = 0.066$], indicating that the avatar was considered most attractive at a slightly higher weight than the own avatar in Experiment 1.

Taken together, Experiment 2 showed that participants were accurate in memorizing and identifying a body of their own weight and shape. Also, it replicated findings of Experiment 1 in what body weight the participants find most attractive: While women with AN preferred a body at about their own weight, controls preferred a body weighing less than their own current weight.

Experiment 3: Replication of Experiment 1

$n = 9$ women with AN and $n = 13$ controls participated in Experiment 3. All participants with AN reported ongoing eating disorder symptoms, and BMI still differed significantly between the groups [AN: $M = 15.87$

Table 3. *Pearson correlations of outcome measures with body mass index (BMI), eating pathology, body dissatisfaction, self esteem, comparison behavior and anxiety before the experiment.*

	Distortion (1AFC)		Distortion (MoA)		Sensitivity to Weight Loss		Sensitivity to Weight Gain		Desired change (MoA)		Desired-*v.*-actual discrepancy	
	AN	Con	AN	Con	AN	Con	AN	Con	AN	Con	AN	Con
BMI (kg/m^2)	0.02	−0.01	−0.22	−0.04	0.02	0.16	0.15	0.43	−0.24	**−0.67****	**−0.44***	**−0.59****
EDE Total	0.09	−0.19	0.12	**−0.41***	0.23	0.42	0.09	0.08	−0.27	**−0.46***	−0.24	**−0.63****
EDE Res	−0.26	−0.07	−0.14	−0.18	0.25	0.37	−0.17	0.10	−0.20	**−0.51***	−0.34	**−0.48***
EDE WC	0.27	−0.32	0.26	**−0.49***	0.13	0.26	0.15	−0.15	−0.13	−0.17	0.04	**−0.52****
EDE EC	0.07	0.12	0.25	−0.18	0.13	0.05	0.11	0.18	−0.40	−0.24	−0.30	−0.29
EDE SC	0.21	−0.02	0.09	−0.20	0.21	0.35	0.22	0.31	−0.21	−0.30	−0.25	−0.34
EDI-2 DT	0.14	−0.20	0.23	−0.27	0.02	**0.43***	0.24	0.05	−0.27	**−0.43***	−0.20	**−0.51***
EDI-2 BD	0.30	0.04	0.31	−0.12	−0.36	0.30	0.21	0.33	**−0.47***	**−0.60***	−0.20	**−0.50***
BIQ-VBD	−0.16	−0.14	−0.06	−0.10	0.17	0.08	−0.05	−0.12	0.34	0.40	0.38	0.14
BIQ-NBE	−0.12	−0.03	0.07	−0.05	−0.16	0.27	0.11	0.29	−0.29	**−0.47***	−0.25	−0.32
RSE	−0.06	0.08	−0.23	0.18	−0.01	−0.28	−0.15	−0.06	**0.49***	0.30	0.36	0.27
PACS	−0.14	−0.03	0.05	−0.06	0.15	0.39	0.22	0.38	−0.29	**−0.47***	−0.40	−0.36
STAI pre	0.20	0.03	0.28	0.03	−0.26	−0.30	0.08	−0.28	**−0.42†**	−0.08	−0.17	−0.01

†$p = 0.05$, *$p < 0.05$, **$p < 0.01$. None of the significant correlations would have survived Bonferroni correction for multiple testing. EDE = eating disorder examination interview (Hilbert & Tuschen-Caffier, 2010; Cooper & Fairburn, 1987), EDE Total, EDE total score; EDE Res, subscale restraint; EDE EC, subscale eating concerns; EDE WC, subscale weight concerns; EDE SC, subscale shape concerns; EDI-2, Eating Disorder Inventory – 2 (Paul & Thiel, 2005); EDI-2-DT, subscale Drive for Thinness; EDI-2-BD, Subscale Body Dissatisfaction; BIQ, Body Image Questionnaire FKB-20 (Clement & Löwe, 1996); BIQ-VBE, subscale vital body dynamics; BIQ-NBE, subscale negative body evaluation; RSE, Rosenberg Self Esteem Scale (Ferring & Filipp, 1996; von Collani & Herzberg, 2003); PACS, Physical Appearance Comparison Scale (Thompson *et al.* 1991; Mölbert *et al.* 2017); STAI, State Trait Anxiety Inventory, State-Form (Laux *et al.* 1981).

(S.D. = 2.79], Controls: $M = 22.14$ (2.52), Difference to Exp 1 AN $Z = -1.007$, $p < 0.32$; Controls $Z = -0.175$, $p < 0.87$). All outcome parameters were similar as in Experiment 1 [AN: mean *Distortion_1AFC* = −8.77, S.D. = 8.61, *Distortion_MoA* = −6.69 (8.39), *Desired-Change* = 5.83 (9.44), *D-v.-A-Discrepancy* = 3.93 (9.22), *beta_left_ln* = 0.85 (1.12), *beta_right_ln* = 1.81 (0.35); Controls: *Distortion_1AFC* = −5.78 (5.21), *Distortion_MoA* = −4.36 (7.63), *DesiredChange* = −6.23 (7.66), *D-v.-A-Discrepancy* = −10.39 (6.97), *beta_left_ln* = 1.58 (0.93), *beta_right_ln* = 1.73 (0.69)]. Mixed ANOVAs revealed the same pattern of group differences, but no significant difference to Experiment 1 (all $p > 0.14$), and this was confirmed by nonparametric tests. This suggests that our results from Experiment 1 were robust over time and independent from the presentation device (3D life-size immersive presentation *v.* 2D desktop presentation).

Discussion

The present study aimed at disentangling perceptual and attitudinal components of BID in AN. To the best of our knowledge, we are the first to use biometric self-avatars in virtual reality to investigate body image in AN. Our methods allowed us to realistically manipulate body weight of personalized avatars and to investigate perception of other bodies in a well-controlled way by changing the identity of the avatar while keeping the underlying body shape identical. Also, we minimized demand characteristics by using psychophysical experiments and by implementing an outside-treatment-setting for our study. According to our observations, women with AN neither see their own body nor other weight-matched persons differently than controls, but they evaluate them differently in terms of what weight is desirable. Hence, while visual perception of their body is normal, attitudinal components of body representation are strongly disturbed. In the clinical context, our findings suggest that patients with AN need support in changing their desired weight and in feeling positive about a normal weight body.

In this study, we investigated a severely affected patient sample. Importantly, all participants with AN were already in treatment and on their way to partial remission, as illustrated by their EDE scores being lower than in other samples of patients with AN (Hilbert *et al.* 2004). However, all women with AN reported anorexia-typical cognitions and behavior as possible in the treatment setting. The control participants were representative for their age, as illustrated by their scores in questionnaires and the EDE interview (Clement & Löwe, 1996; Ferring & Filipp, 1996; von Collani & Herzberg, 2003; Paul & Thiel, 2005; Hilbert & Tuschen-Caffier, 2010).

The manipulation check confirmed that, as expected, participants identified more with their photo-realistic self-avatar than with the weight and shape matched avatar in Experiment 2. The patients' overall lower identification with the avatars can be explained in the context of their eating disorder symptoms: Women with AN reported high body dissatisfaction as well as low experience of vital body dynamics for their own body. Additionally, they were more anxious before the experimental session. Hence, their overall lower identification might express a general 'distance' that participants with AN felt toward their body and also for their avatar.

Body representation has longtime been conceptualized as a hierarchical construct with different components (Berlucchi & Aglioti, 2010; de Vignemont, 2010). As there is no clear evidence for any such distinction (de Vignemont, 2010), a dimensional model has recently been developed (Longo *et al.* 2010; Longo, 2015, 2016). In this notion, body representation is a conglomerate of multiple body representations that can be characterized in terms of how explicit *v.* implicit they are and in how much they are perceptual *v.* conceptual. The body representations are informed by different senses and modalities, such as vision, proprioception or even social comparison and can be integrated into higher-level representations. A benefit of this framework is that it supports a distinction between perceptual and conceptual representations while at the same time considering mutual interactions. From our experimental tasks, we were able to derive different measures of explicit visual body perception. If distorted visual perception or low BMI were the driving factors behind overestimation, we would have expected to observe overestimation in all experiments, whereas overestimation in Experiment 1 only would have suggested demand characteristics or other self-referring processes as driving factors. Interestingly, irrespective of group, participants tended to underestimate their weight in Experiment 1, and there was a trend that this was even more pronounced in women with AN than in controls (cf. Table 2 and Fig. 2). In line with a previous study (Øverås *et al.* 2014), we observed more accurate estimations in Experiment 2, suggesting that mis-estimation of the own size was linked to own identity.

Similarly, none of the sensitivity parameters showed a group effect indicative of a poorer performance in women with AN, and Experiment 3 suggested that this finding is robust. However, there was a trend in both groups to accept thinner avatars as corresponding to the own body, while for the memorized other person in Experiment 2, fatter bodies were more readily accepted as correct. A possible explanation for the underestimation and higher acceptance of thinner bodies as own in Experiment 1 is that participants' memories of their own bodies were influenced by a self-serving bias that is that participants remembered themselves closer to their desired weight (Aars & Jacobsen, 2016). However, this explanation would be discrepant with studies showing that people with an eating disorder tend to focus their attention on body parts perceived as non-attractive when they see their own body, whereas they focus on attractive body parts in other people (von Wietersheim *et al.* 2012; Tuschen-Caffier *et al.* 2015). Alternatively, it is possible that although participants remembered their body accurately, they additionally based their judgments on conceptual representations such as 'this body is lean' or 'I am thin' (Smeets *et al.* 2009). Overall, our observations suggest that body size estimation in women with AN is not generally characterized through a deficit in visual weight representation. However, given that we observe cognitive–attitudinal influences even on allegedly perceptual parameters such as sensitivity (Gardner & Moncrieff, 1988), our observations also emphasize how challenging it is to isolate specific representations of the body through experimental tasks.

A further strategy to investigate whether visual perceptual distortions might underlie BID in AN was to analyze whether distortion or sensitivity correlate with eating disorder symptoms or body dissatisfaction. We observed no significant correlation between the distortion or sensitivity parameters of Experiment 1 with eating disorder symptoms and body dissatisfaction. Further, unlike a previous study, we did not observe that anxiety is associated with overestimation of body size (Øverås *et al.* 2014). Interestingly, we also observed no correlation with BMI, suggesting that in our paradigm, overestimation was neither associated with eating disorder symptoms nor a secondary effect to low BMI (Cornelissen *et al.* 2013, 2015). Several differences between previous studies and the present setup could account for these discrepancies; we used for example a different stimulus presentation method and task instruction.

In line with existing literature (Cash & Deagle, 1997; Mohr *et al.* 2010; Sala *et al.* 2012), we observed a consistent preference of women with AN for severely underweight bodies. While controls' desire for a lower weight can be interpreted as common desire for a slender healthy weight body (Aars & Jacobsen, 2016), the desired weight of women with AN is concerning. Although women with AN had committed themselves to clinical treatment, had expressed insight in their current weight status when estimating their size, and often adjusted a *desired change* in the direction of weight gain, only five women with AN actually adjusted a desired body weighing more than themselves in Experiment 1 (Fig. 2*c*). Notably, more than half (52%) of women with AN desired a body that would have been in the weight range of extreme AN (i.e. BMI below 15), although all women with AN would have been able to adjust the body outside that weight range. Our observations show that although women with AN know about their underweight, they have large difficulties in internalizing a normal weight as goal and in stopping to 'like' their current underweight.

The present study also has limitations: First, although our paradigms allow for strong conclusions on the role of visual perception for body size estimation, we have not examined other sensory modalities. As body representation is a very complex and broad construct (Longo *et al.* 2010; Longo, 2016), it is possible that our paradigm has overlooked nonvisual perceptual disturbances which might be involved in the feeling of being too fat that women with AN often report. Second, while the statistical shape model used in this study is one of the most realistic to date, it was built to represent the shape of a normal weight population and may not perfectly characterize variations in weight at the extreme end of the spectrum. Further, we see a limitation in that we varied participants' bodies in a range of ±20% of their own weight instead of a fixed weight range, e.g. from underweight to normal weight. Although this prevented biases due to Weber's law (Cornelissen *et al.* 2016), it also led to different absolute weight spectrums and limited the range in which participants could adjust their desired body.

Our study contributes to a better understanding of the nature and mechanisms of BID in AN and it has direct implications for the treatment of AN. Our observations contradict the widespread assumption that patients with AN have a perceptual distortion in the sense that they cannot accurately see their own size or perform generally bad in estimating body sizes. Rather, we find evidence that attitudinal components of body image are distorted in AN, as affected individuals consider underweight bodies as desirable and attractive. It remains open whether other sensory modalities contribute to this attitudinal disturbance. According to our observations, interventions should aim at helping patients with AN to change their desired weight and to accept their body in healthy weight. Further studies are needed to explore in more detail at what level of body representation interventions are most promising.

Supplementary material

The supplementary material for this article can be found at https://doi.org/10.1017/S0033291717002008.

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Declaration of Interest

MJB is a co-founder, investor, and member of the board of Body Labs Inc., which is commercializing research on 3D body shape.

Ethical Standards

The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

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Supplementary material to method section of the manuscript "Assessing body image in anorexia nervosa using biometric self-avatars in virtual reality: Attitudinal components rather than visual body size estimation are distorted"

Body scan and stimulus image generation

As described in the main text, we collected body scans using a full body 3D scanning system (3dMD, Atlanta, GA). The scanning system uses speckle projectors which project textured light patterns on the body, 22 stereo units composed of two black and white cameras observing the speckle pattern for recording the body geometry, and a 5-megapixel colour camera capturing the body texture. The system has a spatial resolution of approximately 1 mm. In order to get accurate representations of the participants' body shapes, participants dressed in a standardized set of tightly fitting short grey pants and a grey top and if they had long hair, dressed their hair to a bun. We took three body scans in T-pose, A-pose and neutral pose, resulting in three high-polygon meshes and three RGB images for texture generation.

These meshes were then co-registered to a statistical model of body shape that parametrizes individual shape (Anguelov *et al.* 2005; Hirshberg *et al.* 2012). The statistical body model consists of a template mesh that can be deformed in shape and pose in order to fit a 3D-scan. The shape component of the body model was learned from 2,094 female bodies in the CAESAR dataset (Robinette *et al.* 1999) by applying principal component analysis on the triangle deformations in the observed meshes after removing deformation due to pose. This allowed to model body shape variation in a subspace, U, spanned by the first 300 principal components, where the body shape of an individual, S_j, is described as a vector of 300 linear coefficients, β_j, that approximate the shape deformation as $S_j = U\beta_j + \mu$, where μ is the mean shape deformation in the female population. The pose component of the body model compactly describes deformations due to body part rotations and is trained from approximately 1,200 3D-scans of people in different poses. The registration process consists of the identification of pose and shape parameters that transform the template mesh into the scan by minimizing the distance between template mesh and scan. Once the scan is registered, a texture map is computed for the participant's model based on the pixels from the 22 RGB calibrated images. The final texture map was computed using the median pixels of the three textures. This texture map was later post-processed in Adobe Photoshop (CS6, 13.0.1) to conceal small artefacts and to standardize brightness and the colors of the textures across participants.

In order to generate the different BMI versions of each avatar, a linear regressor X was learned between anthropomorphic measurements A = [weight, height, arm length, inseam] and the shape identity component β for the whole CAESAR dataset, so that the difference $\|(A|1)X - \beta\|$ is minimized. This defines a linear relation between shape and measurements for each participant and allowed us to modify β in a way that produces intended changes in the anthropomorphic measurements. Given each participant's weight w, height h, and registration, nine avatars were generated with varying BMIs $\left(1 + \frac{\Delta BMI}{100}\right)\frac{w}{h^2}$, where ΔBMI = {0, ±5%, ±10%,

±15%, ±20%}. Changing the BMI was achieved by applying a change in the shape vector, so that $\Delta\beta = \left[\frac{\Delta BMI}{100} \mathrm{w}, 0, 0, 0\right] \cdot \mathrm{X}$ (i.e. changing the weight equally to the desired proportional change in BMI, while keeping the other measurements – height, arm length, inseam – constant (see Piryankova et al., 2014 for a more mathematical description). An example of these shape deformations applied to an average body is provided at http://bodyvisualizer.com/ (Max Planck Institute for Intelligent Systems, Perceiving Systems, 2011). To prevent possible effects due to individual pose, pose parameters of all avatars were standardized across participants to an A-pose. The pose parameter vector was calculated as the average pose parameter vector of all registered scans in the A-pose from the CAESAR dataset.

The nine body shapes were then combined in Autodesk 3ds Max 2015 to a single avatar with morph channels such that it was possible to morph between the meshes in steps of 0.05% of the participant's actual BMI. Finally, the body was horizontally flipped in order to enable a second-person (mirror) perspective as opposed to a third-person (photo) perspective on the body.

To generate the artificial other person's avatar for Experiment 2, we used the participant's body meshes, but presented them not with the participant's texture map, but with a standard texture map. This standard texture was generated by combining the median pixels of 1,200 scans used for the pose model (around 50 different women), so that it represents an average person. That way, we obtained an avatar that was completely matched to the participant in terms of height, weight and body shape, but due to different color information appeared like having another identity.

Experimental technical setup

We implemented the experimental setups for both the One-Alternative Forced Choice and the Method of Adjustment Task in Unity 3D (Version 4.6.3f1, Unity Technologies). We placed the participant's mirror-inverted avatar in an empty virtual room at a distance of 2 m from the participant, i.e. 1 m from the screen (Fig 1, left). In Experiment 1 and 2, participants stood at 1 m distance from the screen, so that for them the scene looked like facing themselves in a mirror (see Figure 1). The scene was presented a flat, large-screen immersive display on which the stimuli were projected using a Christie SX+ stereoscopic video projector (1400 x 1050 native pixel resolution). The projected area covered 2.16 m width × 1.62 m height (94.4° x 74° of visual angle) with a floor offset of 0.265 m. The stereoscopic projection was generated using an average interocular distance of 6.5 cm (Willemsen *et al.* 2008). In order to see the scene stereoscopically, participants wore a pair of shutter glasses (nVidia 3D Vision Pro). The glasses had a field of view of 103° × 62°, corresponding to an area of 2.52 m × 1.2 m of the display. The display was connected to a motion tracking system (ART, SMARTTRACK). Although the avatar was a three dimensional object, perspective was locked to frontal view, so that the body could only be seen from the front, but not from the side. Despite limited interaction, the setup scored high on central dimensions of virtuality as described in Milgram and Kishino (1994). Visual angle of the whole avatar was approx. 29.5-32° (torso 8-12°), although it depended on participants' size and the morph width. However, participants were allowed to look around freely.

Figure S1. A+B Illustration of life-size stimulus presentation in Experiment 1 and 3, mimicking the situation of looking at oneself in a mirror. C Screenshot of avatar presentation in Experiment 3

For Experiment 3, we exported the Unity scene for desktop use. Presentation devices were not standardized, but ordinary desktop monitors were used that were placed so that the avatar was shown approximately at participants' eye height. The scene was displayed in full screen mode. Responses were given using the left and right buttons of a computer mouse. During the task, participants were seated, resulting in a weaker mirror illusion due to incongruent size and pose between participants and their avatar.

Experimental procedure

As described in the main document, the experimental session (2) consisted of two blocks, the first containing Experiment 1 and the second containing Experiment 2. In Experiment 1, body size of the avatar with own photorealistic texture was estimated. In Experiment 2, participants estimated the size of a memorized avatar with another identity. To the participants, this avatar was introduced as "another person" without any further explanation. However, the avatar used in Experiment 2 had the identical body shape as the participant, but a standard identity (texture). Experiment 3 contained the same psychophysical tasks and the same avatar as Experiment 1, but the body stimuli were presented on a desktop monitor.

In all experiments, participants completed three tasks: A One-Alternative Forced Choice Task (1AFC) and two Method of Adjustment Tasks (MoA), one referring to the current and one referring to ideal body size. Prior to Experiment 1 and 3, participants were informed that based on the body scan, a set of personalized bodies had been generated that could either represent exactly their body or be gradually shrunk respectively blown up versions of their body. Prior to Experiment 2, participants were informed that they now had to memorize another body. Afterwards, they would be shown correct, blown up and shrunk versions of the body and would have to identify the correct body. Participants were presented with the template body for 2 minutes before the 1AFC task and again for 1 minute before the MoA task.

In the 1AFC task participants were shown their avatar for 2 seconds and afterwards a blue screen with a statement appeared. In Experiment 1 and 3, the statement was “That was my body. (Yes/No)” and in Experiment 2, it was modified to “That was the correct body (Yes/No)”. The wording was chosen as emotionally neutral alternative to frequently used thinner/fatter judgments. No time limit was given for the answer, but participants were instructed to rely on their gut feeling for the answers and to not cogitate much. Answers were given through pressing left and right buttons on a joystick pad that participants held in their hands. As soon as the participant had answered, the next trial started. Avatars were morphed to ± 0%, 5%, 10%, 15% and 20% weight, and each of these nine body shapes was presented 20 times, resulting in a total of 180 trials. The order of the trials was randomized block-wise such that each of the nine different bodies was presented before being presented again. After every 45 trials, participants could take a break if needed.

In the MoA task, participants were shown the avatar with no time limit, and had to adjust it to their current respectively ideal body size. At the beginning of each trial a blue screen with the instruction appeared for 2 seconds, afterwards, the avatar appeared. In Experiment 1 and 3, the instruction was “Please adjust the body until it matches your CURRENT body! (Less / More)”, in Experiment 3 it was modified to “Please adjust the body until it matches THE CORRECT body! (Less / More)”. Participants could again use the left and right button of a joystick pad to do the adjustment, and started the next trial using another button on top of the joystick pad. During the procedure, no time limit was given, and participants were allowed to go back and forth. Each of the nine weight steps used in the 1AFC task was randomly presented once as a start body, resulting in nine trials. Linear morphing was possible continuously in steps of 0.05% of the participant’s BMI, again in the range of ±20%. Finally, for the MoA ideal body, the MoA procedure was repeated, with instructions modified to “Please adjust the body until it matches the CORRECT body” respectively to “Please adjust the body so that it is as ATTRACTIVE as possible”.

Outcome measures

From the different experimental tasks, we extracted for all experiments 1) the degree of inaccuracy/distortion of the estimated body size as compared to participants’ actual weight at the time of the experiment (1AFC and MoA) 2) the sensitivity to weight changes when avatars were morphed to lose and gain weight (1AFC) 3) the desired weight change (MoA) and 4) the discrepancy between desired and actual weight (MoA).

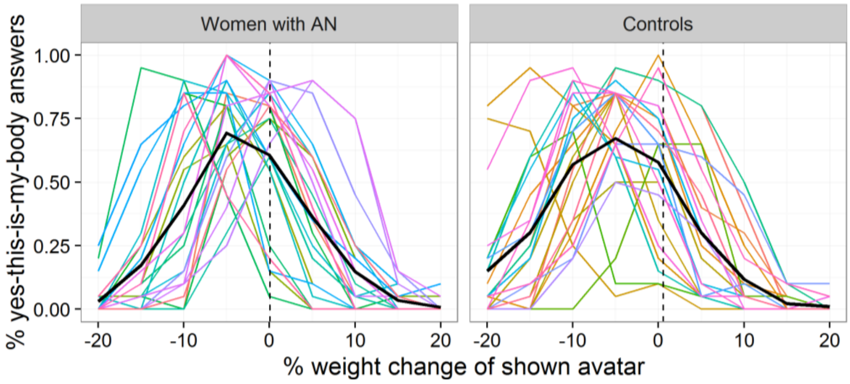

Figure S2. Proportion of yes-this-is-my-body answers depending on the BMI change of the shown avatar for the single participants (colored lines) and average responses (black lines) from the 1AFC task in Exp. 1. The dashed vertical line indicates accurate performance as compared to average weight at the time of the experiment. For the data analysis, we extracted for each participant the peak of the answer distribution as well as the steepness of the answer distribution left and right from the peak.

To quantify the degree of distortion, we computed the over- or underestimation relative to actual individual body weight. Specifically, the formula we used was *distortion = (estimated weight/actual weight at experiment)*100 - 100*. Negative values reflect an underestimation of weight, while positive reflect an overestimation in percent of the participants' actual weight. In the 1AFC task, the weight of the body shape with the highest proportion of yes answers to the statement "This is my body", that is the mode of the distribution of yes-answers over the weight steps was used as the "estimated weight" for the calculation of body size estimation distortion (cf. figure S2). In some cases, two adjacent body shapes had the same amount of yes-answers and then, their average weight was used as mode. In the MoA task, we used the average weight of the adjusted avatars in the nine trials as "estimated weight" to calculate *distortion*. Trials were excluded from the analysis if the estimated body weight was larger than 2 standard deviations from the mean response of the remaining trials per participant and condition (current, ideal), since some participants reported that they had accidentally confirmed the adjusted size before they were finished with their adjustments. This affected 3.7% of all trials in Experiment 1 and 5.4% of all trials in Experiment 2. Due to a technical error discovered after data collection was finished, linear morphing in the MoA task did not always occur between 15% and 5% of participants' weight when decreasing the avatar's weight. We therefore investigated the time course of adjusting the avatar's weight in each trial. Only 3.8% of the final responses (4.5 % in experiment 2) were given under influence of this displaying error. In experiment 1, 30% of the affected trials were from the same person and very consistent. In experiment 2, affected trials were distributed over all participants. Since participants had no time limit for the adjustments, were explicitly instructed to go back and forth until they felt they couldn't do it more accurate, and the time courses also reflected that they followed our instruction, we decided not to exclude these trials as this might have biased the results for people that responded in this range. Sanity checks confirmed that excluding the affected trials did not affect significance levels of any statistical analysis.

As a measure of *sensitivity*, we analyzed the steepness of the curve on both sides of the mode for each participant and experiment. To parametrize the steepness, we fitted cumulative Weibull functions according to Wichmann and Hill (2001) to both sides of the respective answer distributions. Alpha (position of the psychometric function along the x-axis), beta (the slope of the psychometric function), and lambda (the peak of the psychometric function) were free to vary. Gamma (flooring performance) was fixed to zero. In Experiment 1, good fits were yielded with $R^2 = 0.997$ (Min = 0.96, Max = 1.0) on the left side and $R^2 = 0.993$ (Min = 0.95, Max 1.0) on the right side of the answer distributions. The fitting did not succeed for the left side for one woman with AN and for two control participants due to lack of data. Similarly, in Experiment 2, fits were good with $R^2 = 0.996$ (Min = 0.933, Max = 1.0) and $R^2 = 0.992$ (Min = 0.934, Max = 1.0) on the right side.

Desired change of weight was defined as the required percent weight change to make the body the desired/most attractive body as compared to the estimated body. To this end, we computed similar to the procedure for *distortion* how many percent of actual weight the participant desired to lose or gain to make the body the desired one as compared to what she estimated as her current body. Again, the average adjusted "ideal" body weight of the nine trials was used to calculate the desired weight and the average adjusted "current" body from the MoA task was used as "estimated weight". The desired change of weight as computed here can also be interpreted as body dissatisfaction with absolute values reflecting the degree of body dissatisfaction and polarity reflecting whether the participant whishes an upward or downward change.

In order to also obtain a measure of how far the adjusted desired body was off from the actual weight, we additionally computed the *actual-vs-desired discrepancy* as the percent weight discrepancy between the desired body (or most attractive body) and the actual body weight at the experiment. As opposed to the parameter *desired change*, *actual-vs-desired discrepancy* does not express the subjective, explicit wish and direction for weight change, but provides a more objective measure for what weight the participant finds most attractive.

Statistical Analysis

All statistical analyses were conducted using IBM SPSS Statistics 24. As a general check, we first analyzed group differences in age, height, weight, body mass index, questionnaire measures of body dissatisfaction, self-esteem, comparison habits with regard to outer appearance and symptoms of eating disorders using t-tests for normally distributed data and U-tests for non-normally distributed data. We also analyzed group differences in anxiety before the experiment and anxiety in- or decrease throughout the experiment. As a manipulation check, we calculated a mixed analysis of variance (ANOVA) with between-factor group (AN versus Controls) and within-factor experiment (1 versus 2) on similarity ratings of the avatars to check whether participants in both groups really experienced the “other” body as less similar to themselves than the self-avatar with own texture.

We conducted one-sample t-tests to test whether the *distortion* parameters were significantly different from zero, i.e. whether the participants were significantly inaccurate in their estimates. To examine group differences in *distortion*, we calculated univariate ANOVAs with between-subjects factor group (AN versus Controls) *distortion* parameters from both 1AFC and MoA. The *sensitivity* to weight change parameters beta were analyzed together in one mixed ANOVA with between-subjects factor group (AN versus Controls) and side of the peak (left versus right) as additional within-subject factor so that we could assess whether participants of the two groups were equally sensitive to weight changes in the losing and gaining direction. Since sensitivity parameters beta were not normally distributed but significantly right skewed, they were log-transformed prior to the analysis. *Desired change* of weight and *desired-vs-actual discrepancy* were analyzed similarly to the *distortion* parameters: First, one-sample t-tests were used to determine whether *desired change* of weight and *desired-vs-actual discrepancy* differed significantly from zero, and then we used univariate ANOVAs to compare the values between the two groups.

Next, we explored separately for women with AN and controls correlations between the outcome parameters for the self-avatar with own texture and body mass index, body dissatisfaction, self-esteem, comparison habits with regard to outer appearance and symptoms of eating disorders or anxiety before the experiment.

Finally, to assess whether the same pattern of results would reveal in Experiment 2 with the other person’s texture, we repeated the above ANOVAs with experiment (Experiment 1 versus Experiment 2) as an additional within-subjects factor. Experiment 3 was analyzed analogously and parameters were compared to Experiment 1 using the ANOVA with group (AN versus Controls) as between-subjects factor and experiment (Experiment 1 and 3) as within-subjects factor. In average participants’ weight did not change significantly in any of the groups between Experiment 1 and 3 (AN: mean change = +.0.96 BMI units; $Z = -1.01$, $p = .31$; Controls: mean change = +0.07 BMI units; $Z = -0.18$, $p = .86$;). To control for individual weight changes, all outcomes were calculated with respect to current weight.

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Investigating body image disturbance in anorexia nervosa using novel biometric figure rating scales

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Abstract

This study uses novel biometric Figure Rating Scales (FRS) spanning body mass index (BMI) 13.8 to 32.2 kg/m^2 and BMI 18 to 42 kg/m^2 to investigate body image disturbance in women with anorexia nervosa (AN).

Women with AN (n=24) and a community sample of women (n=104) selected their current and ideal body on the FRS and completed additional questionnaires.

Women with AN accurately picked the body that aligned best with their actual weight in both FRS. Controls underestimated their BMI in the FRS 14-32 and were accurate in the FRS 18-42. In both FRS, women with AN desired a body close to their weight and controls desired a thinner body.

Body image disturbance in AN is unlikely to be characterized by a visual perceptual disturbance, but rather by an idealization of underweight in conjunction with high body dissatisfaction. The weight spectrum of FRS can influence accuracy of weight estimation.

Keywords: body size estimation; anorexia nervosa; eating disorders; figure rating scale; body image disturbance

Investigation of different components of body image disturbance in anorexia nervosa using biometric figure rating scales

Body image disturbance is a core feature of anorexia nervosa (AN). It is characterized by a cognitive-affective and a perceptual component: The cognitive-affective component refers to the high influence of body weight on self-evaluation, and the perceptual component refers to a disturbance in the way the low body weight or shape is experienced (Zipfel, Giel, Bulik, Hay, & Schmidt, 2015). Interestingly, distinctive features of the two components are still unknown, specifically in regards to the role of visual perceptual distortions for body image disturbance. To improve the advancement of therapeutic interventions, a deeper understanding of body image disturbance in AN is needed (Farrell, Shafran, & Lee, 2006).

Figure rating scales (FRS) are a common and time-efficient tool for the assessment of body image disturbance in AN. Typically, FRS are paper-pencil tests that present a series of figure drawings ranging from underweight to obese. Participants select the body that corresponds best to (a) their current body and (b) their ideal body. The discrepancy between the two ratings is then used as a measure of body dissatisfaction, that is cognitive-affective disturbance. Approximately half of existing scales additionally allow for coding of the figure that corresponds best to the actual body of the participant. This is typically performed using post-hoc ascriptions of body mass index (BMI; kg/m^2) to the figures, or by using drawings based on anthropometric data (Gardner & Brown, 2010). The discrepancy between estimated current and accurate current figure can then be derived as a measure of perceptual distortion.

Previous studies report inconsistent results on FRS Perceptual Distortion (PD): While in some FRS studies, women with AN overestimated their size

(Moscone, Amorim, Le Scanff, & Leconte, 2017; Sala et al., 2012), another FRS study observed plausible estimates of the current size (Striegel-Moore et al., 2004). Interestingly, the same studies quite uniformly observed that patients with acute AN had low FRS Body Weight Dissatisfaction (BWD) or were similarly weight dissatisfied as controls. Although satisfaction with a low body weight is conceptually related to a desire for low weight and therefore characteristic of eating disorders, it is still unclear how the lack of body weight dissatisfaction reported in FRS could relate to the increased questionnaire body dissatisfaction in AN (Eshkevari, Rieger, Longo, Haggard, & Treasure, 2014; Junne et al., 2016).

Inconsistencies in results from existing studies could partly be due to methodological flaws of current FRS used. For example, existing scales are often not based on biometric data (Gardner & Brown, 2010) resulting in implausible body shapes, especially in the extreme weight spectrums, and non-linear weight increases between the figures. This is problematic for coding the figure that corresponds best to the participant's actual body and hence for the calculation of perceptual distortion, as validity of post-hoc weight assignments to the figures is not guaranteed. Some scales used silhouettes based on biometric data (e.g. Gardner, Jappe, & Gardner, 2009), however their drawings tend to be very abstract. Lastly, there is minimal literature regarding whether the selection of figures is confounded by response biases stemming from the range presented. Doll, Ball and Willows (2004) demonstrated in healthy participants that presenting figures in ascending order may lead to smaller estimates of current size; however, so far it is unknown how different ranges affect body size estimates.

We developed two novel biometric FRS to overcome methodological flaws of previous FRS in the investigation of perceptual distortion and body weight dissatisfaction in AN and to test for effects of presented weight range of the FRS.

Specifically, we asked (1) How do FRS BWD and FRS PD differ between women with AN and women from the general population? (2) How are FRS BWD and FRS PD associated with questionnaire measures of body dissatisfaction and eating disorder symptoms? and (3) Does the range of the presented scale influence FRS BWD and FRS PD in persons with AN and control participants?

Method

Construction of the FRS 14-32 and FRS 18-42

To construct our biometric FRS, we made use of a statistical body model of average shape variation in the female population (Anguelov et al., 2005) that is learned from 3D body scans of 2094 female bodies from the Civilian American and European Surface Anthropometry Resource project (CAESAR dataset; Robinette, Daanen, & Paquet, 1999). Using the statistical body model, we varied the average female shape to have a specific BMI while keeping arm and leg length fixed. For the FRS 14-32, we generated nine average female bodies with a BMI 23 kg/m^2 ±10%, ±20%, ±30% and ±40% (BMI 13.8 kg/m^2 to 32.2 kg/m^2), thereby centering symmetrically around the average German woman's BMI (*Mikrozensus - Fragen zur Gesundheit - Körpermaße der Bevölkerung*, 2014) and covering extreme underweight to the lower end of obesity. However, as this scale overemphasized underweight as opposed to overweight, we generated the FRS 18-42 as a second scale being more representative for the general population. The FRS 18-42 consisted of nine average female bodies with a BMI 30 kg/m^2 ±10%, ±20%, ±30% and ±40% (BMI 18 kg/m^2 to 42 kg/m^2).

Bodies were rendered in Autodesk 3ds Max 2015 with the preset global lighting setups and a white background, and afterwards arranged and aligned by the body center in Adobe InDesign CS5 (Figure 1). Each body series was presented twice on one sheet in landscape format, together with instructions to select the body that best represented their current and ideal body. Formatted scales are provided in the supplement, further materials are available upon request from the first author. Answers were coded one to nine from left to right. Based on each participant's BMI, we later additionally determined the number of the figure that actually best aligned with the participant's current body. This accurate current body was compared to the estimated current body to calculate FRS PD.

Participants

Participants of the study were women diagnosed with AN (n=24). They were recruited through the inpatient and outpatient service of the Department of Psychosomatic Medicine and Psychotherapy at the University Hospital Tübingen. AN diagnosis was determined based on ICD-10 criteria (*ICD-10-GM - Systematisches Verzeichnis*, 2014) that were assessed by a clinical interview (German version of EDE; Hilbert & Tuschen-Caffier, 2010). Additionally, we assessed a community sample of women (n=104) from the area around Tübingen, Germany. All data were recorded anonymously. The study was approved by the ethics committee of the University Tübingen and the Medical Faculty Tübingen.

Measures

We computed FRS BWD as estimated current minus ideal body, and FRS PD as estimated current minus accurate current body, so that positive values reflect a desire to lose weight respectively weight overestimation (Figure 1). Along with the FRS, we administered German versions of the "Drive for Thinness" and "Body Dissatisfaction" scales of the Eating Disorders Inventory (EDI-2; Paul & Thiel, 2005), the Body Image Questionnaire (BIQ-20; Clement & Löwe, 1996) , the Eating

Disorders Examination-Questionnaire (EDE-Q; Hilbert & Tuschen-Caffier, 2006) and the Physical Appearance Comparison Scale (PACS; Mölbert, Hautzinger, Zipfel, & Giel, 2017). Further, age, height and weight of participants from the community sample were assessed through self-report. Women with AN were measured and weighed at the university hospital.

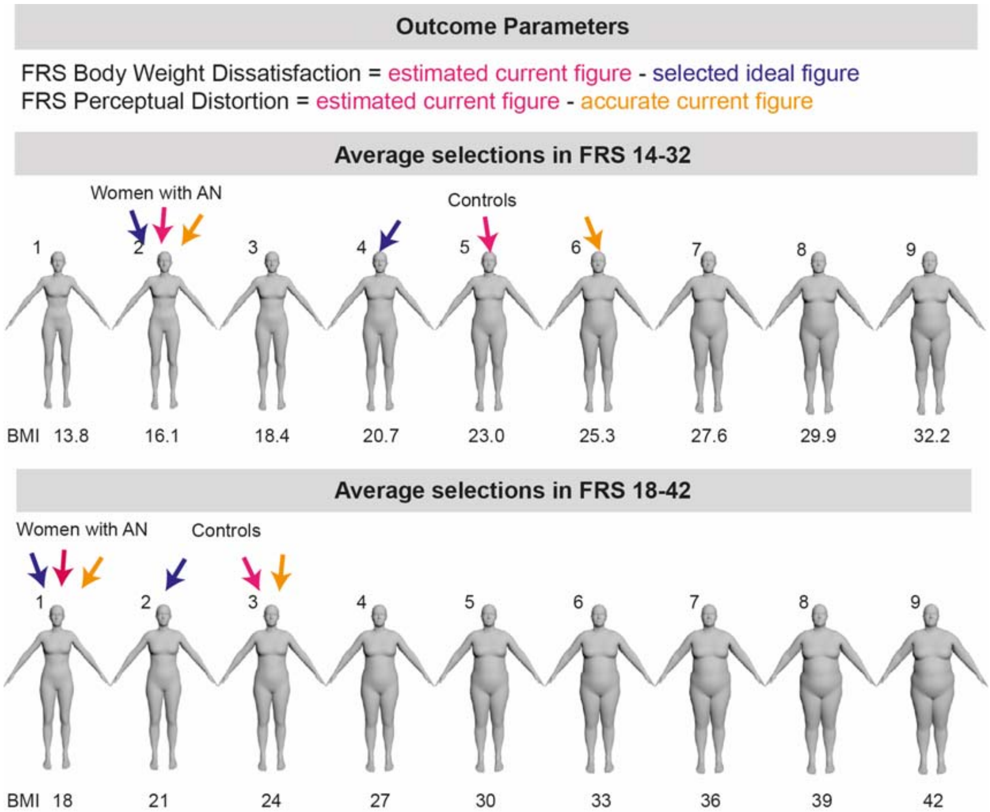

Figure 1. Outcome parameter illustration, figure coding, and average estimated current body (pink), selected ideal body (blue), and accurate current figure (orange) for each group and Figure Rating Scale (FRS). The two FRS were presented on separate sheets without scale name, coding schema and figure body mass index (kg/m^2; BMI). Sample files are provided in the supplement.

Analysis

Because most variables were not normally distributed, we used nonparametric tests to analyze the data. To test whether questionnaire measures, FRS BWD and FRS PD differed between women with AN and women from the community, Mann-Whitney-U-Tests were used. Spearman correlations between the assessed parameters were also calculated. As 17 women with AN and 61 controls filled out both FRS, we also directly compared the two scales using group wise Wilcoxon Rank tests.

Results

As depicted in Table 1, women with AN differed significantly from women from the community sample in terms of a lower BMI, more eating disorder symptoms, and higher levels of questionnaire body dissatisfaction and habitual comparison of their physical appearance. FRS BWD was lower in women with AN than in controls: While controls selected on average a body with a lower BMI than their estimated current BMI as ideal body, women with AN tended to select the same body as their estimated current and ideal body. FRS PD differed between the groups only in the FRS 14-32. Women with AN were accurate, but controls underestimated their size by in average one figure. In the FRS 18-42, both women with AN and controls accurately estimated their body weight with no significant difference (Figure 1). Notably, in the FRS 14-32, women with AN selected the second lowest body as estimated current and ideal body, suggesting that the low FRS BWD and accurate FRS PD were not caused by a floor effect due to insufficient scale range.

	Women with AN						Community Sample								
	N	Mean	SD	Median	Min	Max	N	Mean	SD	Median	Min	Max	Z	*p*	r
Age	24	23.29	5.66	21.00	19	39	104	24.70	6.50	23.00	19	56	-2.169	<0.03	0.19
Body Mass Index (kg/m²)	24	15.07	1.62	14.97	12.38	17.96	104	23.90	6.07	22.17	16.94	43.89	-7.500	<0.001	0.66
FRS 14-32 PD	23	0.22	1.04	0	-2	3	62	-1.15	1.02	-1	-3	1	-4.611	<0.001	0.50
FRS 18-42 PD	18	0.33	0.97	0	0	4	104	0.12	1.05	0	-3	3	-0.588	<0.56	0.05
FRS 14-32 BWD	23	-0.17	1.67	0	-2	5	62	0.87	1.21	1	-1	4	-3.305	<0.001	0.36
FRS 18-42 BWD	18	-0.28	1.23	-1	-1	4	103	1.46	1.73	1	-2	8	-4.906	<0.001	0.45
EDE-Q Total Score	24	2.95	1.66	2.96	0.08	5.75	104	1.13	1.13	0.66	0	4.73	-4.793	<0.001	0.42
EDI-2 BD	24	36.08	9.23	36.5	14	54	104	30.56	11.16	31.0	10	54	-2.199	<0.03	0.19
EDI-2 DT	24	28.83	9.41	31.5	9	42	104	18.28	8.49	17.0	7	40	-4.476	<0.001	0.40
BIQ-20 NBE	24	33.94	9.49	33.5	17	50	104	23.80	8.69	22.0	10	50	-4.338	<0.001	0.38
BIQ-20 VBD	24	28.23	5.58	30.0	15	39	104	33.40	5.93	34.0	18	48	-3.579	<0.001	0.32
PACS	24	17.00	3.04	17.0	11	21	103	14.61	3.58	14.0	7	23	-2.963	<0.003	0.26

Table 1. Sample characteristics, questionnaire data and figure rating task parameters for women with AN and controls. Group differences were tested for significance using Mann-Whitney-U-Tests. p-values were considered significant at Bonferroni-corrected .05 level. Effect size r (Z/SQRT(N)) is considered small at 0.1, medium at 0.3 and large from 0.5 on. FRS PD = FRS Perceptual Distortion; FRS BWD = FRS Body Weight Dissatisfaction; EDE-Q = Eating Disorder Examination Questionnaire; EDI-2 BD = Eating Disorder Inventory 2 Subscale Body Dissatisfaction; EDI-2 DT = Eating Disorder Inventory 2 Subscale Drive for Thinness; BIQ-20 NBE = Body Image Questionnaire 20 Subscale Negative Body Evaluation; BIQ-20 VBD = Body Image Questionnaire 20 Vital Body Dynamics; PACS = Physical Appearance Comparison Scale.

Table S1 provides an overview on the correlations between FRS parameters and questionnaires in both groups. In both groups, FRS BWD correlated moderately to strongly with questionnaire body dissatisfaction and eating disorder symptoms as assessed by the EDE-Q, although more consistently in the control group than in women with AN. FRS PD correlated weakly with some questionnaire scales in the control group. In women with AN, significant correlations with FRS PD occurred only in the FRS 18-42 and with EDI-2 scales. These correlations were not present in the FRS 14-32, suggesting that they were due to the insufficient scale range of the FRS 18-42 if women with AN wanted to indicate a lower ideal than current body weight.

The direct comparisons of both scales revealed that in women with AN, neither FRS BWD nor FRS PD depended significantly on the range of the scale (FRS BWD $Z = -0.28$, $p < 0.78$; FRS PD $Z = -0.30$, $p < 0.76$). In controls, FRS BWD was stable, but FRS PD was significantly larger in the FRS 14-32 than in the FRS 18-42 because controls on average underestimated their weight in the FRS 14-32 (FRS BWD $Z = -0.21$, $p < 0.84$; FRS PD $Z = -6.31$, $p < 0.001$).

Discussion

In this study, we used novel optimized biometric FRS to better characterize body image disturbance in AN. As opposed to previous scales, our FRS reflect weight-related shape differences of average women and allow for accurate comparisons with the participant's actual body. We observed that women with AN reported no body weight dissatisfaction in the FRS, but general body dissatisfaction in the questionnaires. Women with AN accurately identified their current weight, while controls underestimated their weight in the FRS 14-32. In line with previous studies, we conclude that body image disturbance in women with AN is likely not characterized by non-awareness of their own weight, but rather by other factors such as for example high body dissatisfaction and desired low weight (Gardner & Bokenkamp, 1996; Gardner & Moncrieff, 1988; Phillipou et al., 2016; Smeets et al., 2009).

With regard to their eating disorder symptoms, as indicated by the EDE-Q total score, both our community sample and our sample of women with AN can be considered representative (Hilbert, de Zwaan, & Braehler, 2012). Women with AN also scored higher on the EDI-2 scales and the BIQ-20 Negative Body Evaluation, thereby replicating previous observations (Albani et al., 2006; Paul & Thiel, 2005). Conversely, women with AN reported lower FRS BWD than controls, although FRS BWD and questionnaire body dissatisfaction were highly correlated in both groups.

This apparent contradiction resolves when taking into account that instruction-wise, FRS BWD refers highly to weight whereas questionnaire BWD does not. As the displayed bodies in FRS vary in weight only, participants logically base their judgments mainly on weight and hence FRS BWD likely reflects weight regulation desires. Questionnaire body dissatisfaction, on the other hand, refers to more detailed facets of self-concept such as evaluations of single body parts or appearance related fears. In patients with AN, degrees of high to very high questionnaire body dissatisfaction seem to go along with either the desire for a slight weight gain or further weight loss. In controls, degrees of low to middle questionnaire body dissatisfaction are associated with a desire for low to moderate weight loss. Hence, despite of the low average FRS BWD in women with AN, FRS BWD seems to be a valid indicator of body weight dissatisfaction and could serve as a sensitive predictor of weight gain in treatment (Boyd et al., 2017). However, it should be interpreted as one aspect of body dissatisfaction only, rather than as a general indicator.

Notably, we did not find any evidence for a perceptual distortion in AN. In both FRS, patients with AN accurately selected the body that best aligned with their current weight. This was even the case in the FRS 14-32 where participants correctly selected the second lowest body out of three underweight figures, suggesting that the accurate performance was not due to a mere floor effect. Control participants tended to underestimate their weight, but only if the correct answer would have required them to select a body above the middle of the scale as "current" body. In other words, as long as the scale roughly represented them at the correct position in the range, controls were accurate, as well. This suggests that our FRS are generally valid tools to assess visual weight perception, although the range of the scale can influence accuracy. Future studies should investigate whether the effect of scale range could be neutralized, for example by random rather than ascending presentation of figures.

In conclusion, this study highlights the potential of biometric FRS: As long as scales are roughly representative of the participants' weight and position in range, FRS can be valid measures of current weight and body weight dissatisfaction. Furthermore, our study contributes to an improved understanding of body image disturbance in AN. While women with AN did not exhibit any visual perceptual difficulties in identifying their weight on the FRS, we observed a strong cognitive-affective disturbance characterized by an idealization of underweight in conjunction with high body dissatisfaction. Further exploration of the association between satisfaction with weight and with the body in general could reveal new therapeutic options for AN.

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	Women with AN				Controls			
	FRS Body Weight Dissatisfaction Estimated-Ideal Figure		FRS Perceptual Distortion Estimated-Actual Figure		FRS Body Weight Dissatisfaction Estimated-Ideal Figure		FRS Perceptual Distortion Estimated-Actual Figure	
	FRS 14-32	FRS 18-42	FRS 14-32	FRS 18-42	FRS 14-32	FRS 18-42	FRS 14-32	FRS 18-42
EDE-Q Total	.30	**.50***	.00	.42	**.68****	**.64*****	.22	**.31***
EDI-2 DT	**.76****	**.80****	.29	**.49***	**.70****	**.66*****	**.28***	**.32***
EDI-2 BD	**.44***	**.54***	.22	**.55***	**.72****	**.71*****	**.31****	**.34****
FKB-20 PBD	**-.44***	-.40	-.22	-.20	-.18	-.12	-.21	-.19
FKB-20 NBE	.20	.26	.07	.33	**.59****	**.61*****	.17	.22
PACS	.39	.29	-.07	-.21	.13	.08	.23	**.27****

Supplement 1. Spearman correlations between figure rating scale parameters Body Weight Dissatisfaction and Perceptual Distortion with questionnaire measures of eating disorder symptoms, body dissatisfaction, and physical appearance comparison habits.

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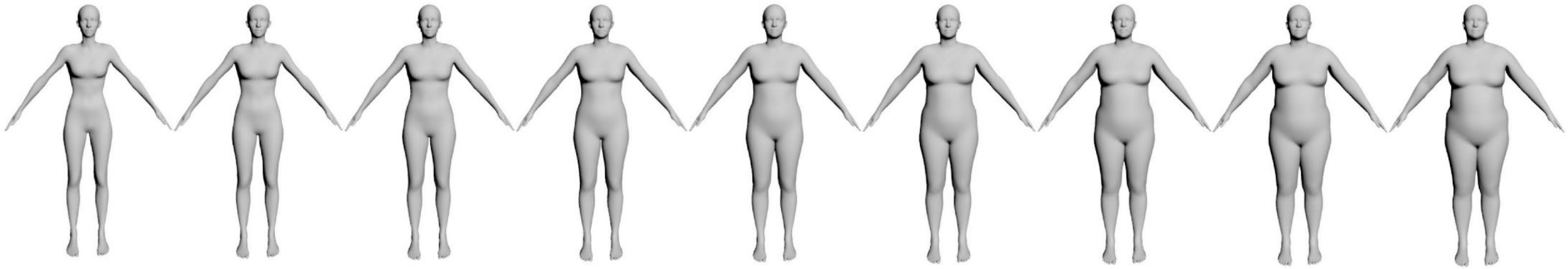
Please select the body that matches **your current body** best.



Bitte markieren Sie den Körper, der **Ihrem idealen Körper** am ehesten entspricht.
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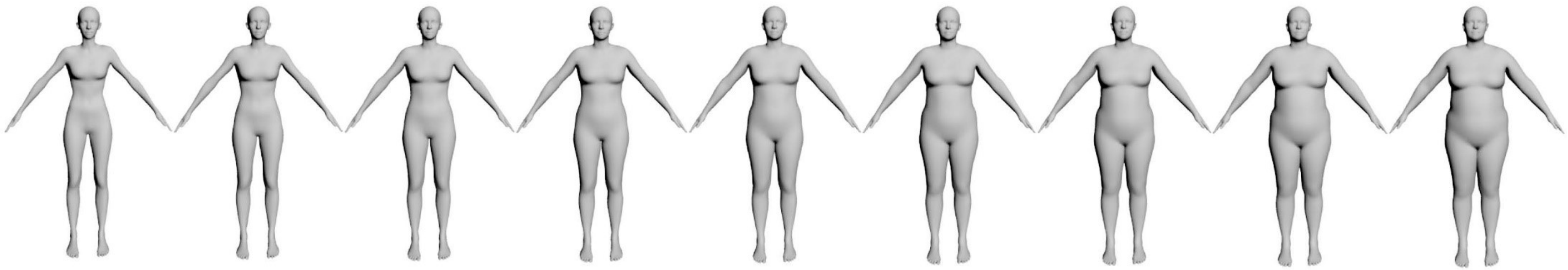

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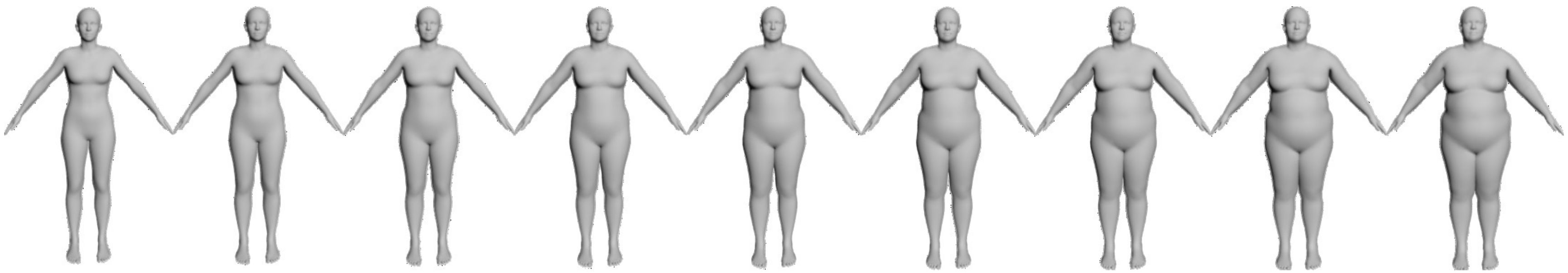

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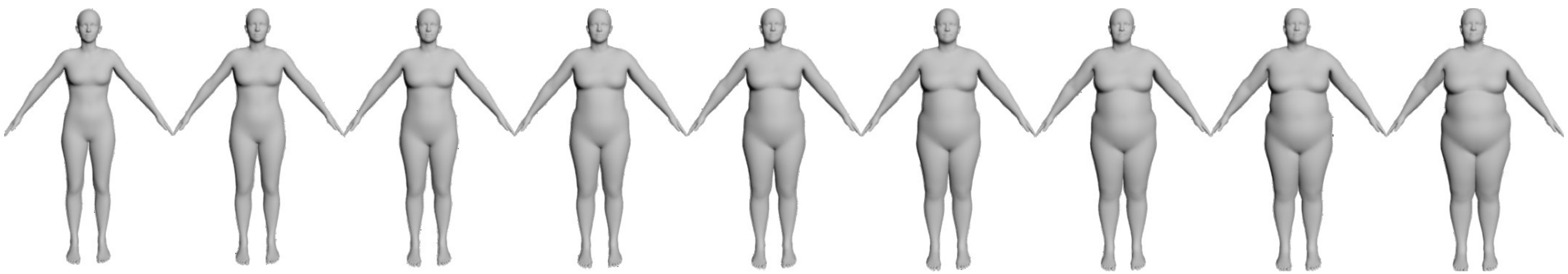

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