Body image; representation and constraints on measurement in real and virtual worlds

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Abstract

Body image is a multidimensional construct that embraces a person's conscious perception of their physical self, including the thoughts and feelings that result from that perception. Disturbed body image can lead to dramatic attempts by the individual to alter their appearance, for example through self-starvation in eating disorders such as anorexia nervosa. Body image comprises two independent modalities: i) a perceptual component that has to do with the accuracy with which a person can judge the dimensions of their own physical appearance, and ii) an attitudinal component which captures the feelings that a person has about their body size and shape. This thesis explores perceptual body image, with a focus on body size estimation, in samples of non-eating disordered women from three points of view.

Firstly, individuals who have eating disorders are known to experience a diverse range of disturbances in body representation. In study one, we sought to investigate how attitudinal and perceptual body image may normally be expected to interact with motoric representations in the body scheme. To this end we tested a moderated mediation model which showed that perceptual body image only mediated performance on an egocentric motor imagery task in women with raised body image concerns and low self-esteem. We concluded that the affective salience of a distorted body representation mediates the degree to which it is incorporated into the current body state.

Secondly, in studies 2-4 we used a modified version of the Bubbles masking technique, in combination with eye movement recording, to discover the visual cues that women use to make perceptual body image judgements. We found that although observers fixate centrally on the torso when making body size judgements, nevertheless they direct their visual attention to the edges of the torso, to gauge width as an index of body size. Based on this dissociation, we conclude that central fixations are simply the most efficient way of positioning the eye to make size judgements.

Next, in studies 5 and 6, we investigated the feasibility of body size estimation using 3D stimuli in immersive virtual reality (VR). In a sequence of experiments, we show: i) how a bespoke avatar can be created from 2D photographs; and validated ii) that participants can identify the presence of their own avatar amongst others, despite anonymization by facial masking; iii) that participants are more accurate at estimating their body size with a bespoke avatar than a standard 3D model in VR. Lastly, in study 7 we replicated and extended an existing body image intervention, known to work in 2D on a flat panel monitor screen, by testing it in VR. We successfully raised individuals' perceptual boundary for thin versus fat body sizes. This perceptual retraining led to reductions in psychological concerns about body shape, weight and eating; effects that persisted for up to two weeks post-training, some of which were more potent in VR than 2D.

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List of acronyms

AN – Anorexia Nervosa
ANSD – Anorexic Spectrum Disorder
BDI – Beck Depression Inventory
BN – Bulimia Nervosa
BMI – Body Mass Index
BSQ – Body Shape Questionnaire
CBT – Cognitive Behavioural Therapy
CGI – Computer Generated Imagery
DL – Difference Limen
ED(s) – Eating Disorders
EDE-Q – Eating Disorders Examination Questionnaire
HSE – Health Survey England
JND – Just Noticeable Difference
MoA – Method of Adjustment
POV-1 – Point of View, first person perspective
POV-3 – Point of View, third person perspective
RHI – Rubber Hand Illusion
PSE – Point of Subjective Equality
RSE – Rosenberg Self-Esteem Scale
SDT – Signal Detection Theory
SES – Socio-Economic Status
VDT – Video Distortion Technique
VR – Virtual Reality

Published work

Chapter 3:

Irvine, K., McCarty, K., McKenzie, K. J., Pollet, T. V., Cornelissen, K. K., Tovée, M J., & Cornelissen, P. L. (2019). Distorted body image influences body schema in individuals with negative bodily attitudes*. Neuropsycholgia, 122, 38-50.*

Chapter 4:

Irvine, K., McCarty, K., Tovée, M. J., Pollet, T. V., Cornelissen, K. K., & Cornelissen, P. L. (2019). The visual cues that drive the self-assessment of body size: dissociation between fixation patterns and the key areas of the body for accurate judgement. *Body Image, 29, 31-46*

Chapter 5:

Irvine, K., Irvine, A., McCarty, K., Cornelissen, K. K., & Cornelissen, P. L. (in prep). Comparison of psychophysical body size estimation tasks in 2D and 3D Immersive Virtual Reality. *Body Image.*

Chapter 6

Irvine, K., Irvine, A., McCarty, K., Cornelissen, K. K., & Cornelissen, P. L. (in prep). A virtual reality interactive training programme to treat body image disturbance. *Body Image*

The following scientific communications have also arisen from this programme of work:

Irvine, K. R., McCarty, K., Cornelissen, K. K., & Cornelissen, P. L. (2018). *Mind the gap: Distorted body image influences body schema in individuals with negative bodily attitudes* – Poster presented at Appearance Matters Conference, Bath.

Irvine, K., McCarty, K., Cornelissen, K. K., & Cornelissen, P. L. (2017). *"Measuring body image: quantifying agreement*" – Poster presented at PsyPag, 2017, Northumbria University.

Irvine, K., McCarty, K., Cornelissen, K. K., & Cornelissen, P. L. (2017). "*Measuring body image: quantifying agreement*" – Poster presented at Northumbria Faculty of Health and Life Sciences Research Conference, Northumbria University

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This is not the end, it is only the beginning…

Author's declaration

I declare that the work contained in this thesis has not been submitted for any other award and that it is all my own work. I also confirm that this work fully acknowledges opinions, ideas and contributions from the work of others.

Any ethical clearance for the research presented in this thesis has been approved. Approval has been sought and granted by the Faculty of Health and Life Sciences ethics committee at University of Northumbria in Newcastle.

I declare that the word count of this thesis is 60012 words.

SIGNED:

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Chapter 1: Introduction

The first section of this thesis is intended as a general background and introduction to the concepts of body image and eating disorders pathology. We first present the diagnostic criteria of eating disorders, followed by a review of the concept of body image, followed by body schema and lastly eating disorders treatment. At the start of each experimental chapter we also present introductions which contain more specific and detailed information pertaining to the study in question.

1.1 Conceptualising body image

From the outset, definitions of body image seem to capture two broad concepts: i) a perceptual component: "*the picture of our own body which we form in our mind, i.e. the way in which the body appears to ourselves*" and ii) a cognitive/social/evaluative component: "*socially derived attitudes towards particular physical shapes, as well as intrapsychic experiences such as conflicts, defences, beliefs and emotions related to the body*" (Schilder, 1935 as reported in Garner, Garfinkel, & Bonato, 1987, p.119; see also Kolb, 1962, as reported by Schonfeld, 1966). This distinction persists in contemporary definitions; body image has been described as a multidimensional construct, comprising two independent modalities: i) a perceptual component, i.e. the way one sees their own body, an internal picture that may not always be an accurate reflection of how one actually looks like, ii) an attitudinal component (also known as affective-cognitive component), i.e. the way one feels about their body (Cash & Deagle, 1997).

Body image is developed, and continuously changed, by complex interactions between psychological, neurophysiological, and socio-cultural factors, e.g. societal depictions (peers and family), views of physical beauty (e.g. media), and culture and cultural standards; it is central to one's self-concept and influences our psychology and behaviour (Cash & Pruzinsky, 2002; Castle & Phillips, 2002; Cash & Smolak, 2011; Stice 2002).

Some experience positive body image, a multi-faceted construct which includes body appreciation, acceptance, love etc.; it is separate from negative body image, in that positive body image is not simply indicative of low levels of negative body image (Tylka & Wood-Barcalow, 2015a). After extracting shared variance with body dissatisfaction positive body image has been found to have unique associations with well-being, self-care and eating behaviours (Andrew, Tiggemann, & Clark, 2014; Avalos, Tylka, & Wood-Barcalow, 2005; Tylka & Wood-Barcalow, 2015b). While positive body image has received increased attention in the last decade or so, the majority of research has focused on negative body image due to its particular relevance to eating pathology. Nevertheless, negative body image, where one experiences unpleasant feelings and/or thoughts with regard to one's body (i.e. body dissatisfaction), is not exclusive to eating disordered populations. Particularly, in countries with high socio-economic status (SES) and those influenced by Western culture, the phenomenon has been described as "normative discontent", where women report elevated rates of body image disturbance and disordered eating (Bearman, Presnell, & Martinez, 2006; Monteath & McCabe, 1997; Rodin, Silberstein, & Striegel-Moore, 1984; Schaefer et al., 2018; Swami et al., 2010; Wildes, Emery, & Simons, 2001). Bruch (1962) was first to formally recognise the importance of body image for eating disorders. Body image disturbance, encompassing both components of body image in the forms of perceptual distortion and cognitive-evaluative dysfunction are core features of both Anorexia Nervosa and Bulimia Nervosa. Dysfunctional body image is included in the diagnostic criteria of both anorexia nervosa and bulimia nervosa (APA, 2013; Cash, 2002).

1.2 Body image pathology: eating disorders

The clinical importance and relevance of body image is particularly pertinent in eating disorders such as Anorexia and Bulimia Nervosa. Before delving into a detailed description of body image, for context, the following section introduces the diagnostic criteria for Anorexia and Bulimia according to the DSM-5 (APA, 2013).

1.2.1 Diagnostic criteria

Anorexia Nervosa (AN)

A. Restriction of energy intake relative to requirements, leading to a significantly low body weight in the context of age, sex, developmental trajectory, and physical health. Significantly low weight is defined as a weight that is less than minimally normal or, for children and adolescents, less than that minimally expected.

B. Intense fear of gaining weight or of becoming fat, or persistent behaviour that interferes with weight gain, even though at a significantly low weight.

C. Disturbance in the way in which one's body weight or shape is experienced, undue influence of body weight or shape on self-evaluation, or persistent lack of recognition of the seriousness of the current low body weight.

The DSM-V further recognises two subtypes of AN:

Restricting type, where in the last 3 months the individual has not engaged in recurrent episodes of binge eating or purging behaviour (i.e., self-induced vomiting or the misuse of laxatives, diuretics, or enemas). Whereas in the Binge-eating/purging type the individual has engaged in those behaviours over the last 3 months. Furthermore DSM-V specifies that the Restricting type describes presentations in which weight loss is accomplished primarily through dieting, fasting, and/or exercise. The criteria also specify severity of AN, for adults based on Body Mass Index (BMI) and for children and adolescents on BMI percentile. The ranges depend on the BMI as derived from the World Health Organisation (WHO) categories for thinness: mild (BMI ≥ 17), moderate (16 - 16.99), severe (15 - 15.99) and extreme (<15). The level of severity may be increased to reflect clinical symptoms, the degree of functional disability, and the need for supervision.

Bulimia Nervosa (BN)

A. Recurrent episodes of binge eating. An episode of binge eating is characterised by both of the following:

1. Eating, in a discrete period of time (e.g. within any 2-hour period), an amount of food that is definitely larger than what most individuals would eat in a similar period of time under similar circumstances.

2. A sense of lack of control over eating during the episode (e.g. a feeling that one cannot stop eating or control what or how much one is eating).

B. Recurrent inappropriate compensatory behaviours in order to prevent weight gain, such as self-induced vomiting; misuse of laxatives, diuretics, or other medication; fasting; or excessive exercise.

C. The binge eating and inappropriate compensatory behaviours both occur, on average, at least once a week for 3 months.

D. <u>Self-evaluation is unduly influenced by body shape and weight</u>.

E. The disturbance does not occur exclusively during episodes of anorexia nervosa.

1.3 Components of body image: Attitudinal

Broadly speaking, the attitudinal component of body image encompasses body-related emotions and feelings (affect) as well as thoughts and beliefs (cognitions/attitudes), i.e. how someone *feels* they look like and how someone *thinks* they look like respectively (Cash & Smolak, 2011). Attitudinal body image encompasses at least two dimensions: body image evaluation and investment. Cash (1994) investigated 11 different attitudinal body image measures on a sample of 279 college women. A principal component analysis revealed 2 factors, factor 1 included loadings pertaining to *evaluation/affect* (cognitive appraisals and associated emotions about one's appearance) which explained 53% of variance, while factor 2 pertained to *appearance investment* and explained 14% of the variance. Body image *evaluation* refers to appraisal of one's own appearance and the associated satisfaction and beliefs, or indeed any emotions stemming from such appraisal. The degree to which an individual's self-worth may be affected by self-evaluation depends on their body image *investment*. This relates to the importance of appearance to one's self-concept, i.e. the cognitive, behavioural and emotional importance of body appearance for self-evaluation (Bell & Rushforth, 2008).

Negative attitudinal body image concerns negative self-evaluation and attitudes, often referred to as body dissatisfaction, and to feelings of unease or distress (such as low self-esteem and depression) with regards to own body shape, size or appearance (Castle & Phillips, 2002). Dissatisfaction has been described as the discrepancy between the actual and ideal/desired body (Polivy & Herman, 2002). This definition, however, is limited in that it does not include those who may physically be close to their ideal shape and size, yet may still not be satisfied. It may be useful to differentiate between the concepts of body dissatisfaction and body importance. High body importance is the over-concern of body-appearance whereas body dissatisfaction refers to negative subjective perceptions and attitudes about one's body (Cash & Pruzinsky, 2002; Stice & Shaw, 2002).

Negative attitudinal body image can range from mild feelings of dissatisfaction or unattractiveness to extreme obsession with physical appearance that impairs functioning (Bell & Rushforth, 2008). In some, this may lead to drastic behaviours such as excessive dieting, over-exercise, purging, starvation, cosmetic surgery or steroid use to change the way one looks (Pope, Phillips, & Olivardia, 2000; Slevec & Tiggemann, 2010). However, while body dissatisfaction and body-controlling behaviours, such as dieting, are implicated as important components in the aetiology of eating disorders, it is important to note that in themselves they are not sufficient conditions for an individual to develop an eating disorder. In other words, many people may believe that their actual body shape is disparate from their ideal, yet may be accepting of that, while others who may express real body dissatisfaction or actively diet do not develop eating disorders (Polivy & Herman, 2002). This suggests that additional psychological influences are necessary for eating pathology to develop.

1.3.1 Socio-cultural models

The socio-cultural explanations of body image disturbance and eating pathology are the most discussed and perhaps most empirically validated of all body image theories; there are different variants, all of them attempt to explain how the socio-culturally transmitted body ideals lead to body image and eating disturbances (Tiggemann, 2011). The socio-cultural theories suggest that body ideals are socially constructed within a particular culture. Research evidence supports the existence of socio-culturally constructed ideals (Tiggemann, 2011). For example, the female body ideal has changed since the 1950s, becoming increasingly smaller/thinner, indicated by the decreasing size and weight of fashion magazine models and Playboy centrefold models (Sypeck, Gray, & Ahrens, 2004; Voracek & Fisher, 2002). Furthermore, those ideals are transmitted via a variety of socio-cultural channels (media, peers, family), e.g. the aforementioned fashion magazine for women, or Playboy for men. These ideals may then be internalised by individuals who then apply them to themselves or indeed others. According to the socio-cultural models, satisfaction with appearance then serves as a function of the extent to which individuals do or do not meet these ideals (Tiggemann, 2011). If such messages are internalised and developed into a drive to achieve unrealistic standards, for some, this may result in negative body image and the development of unhealthy behaviours to change the way one looks (Slevec & Tiggemann, 2010).

The Dual Pathway Model of eating pathology

Stice and Agras (1998) proposed a conceptual model of eating pathology, the dual pathway model (see **Figure 1.1**. overleaf). To do this, Stice and Agras (1998) drew from the accounts of socio-cultural, dietary and affect-regulation accounts of bulimia, as well as research suggesting the particular involvement of thin-ideals in body dissatisfaction, dieting behaviour and the onset of bulimic symptoms (Stice, 2001; Stice & Agras, 1998; Stice, Mazotti, Krebs, & Martin, 1998; Stice & Shaw, 1994). The model proposes that socio-cultural pressure for thinness, e.g. from significant others or from media that associates thinness with well-being and success in life, together with internalisation of the thin-ideal stereotype, leads to body dissatisfaction. According to the model, such dissatisfaction arises as a result of the inability to attain the impossible ideal body stereotype. There are a number of benefits that are promised when the standards are achieved, such as happiness, health, and self-esteem (Bordo, 1993), therefore, inability to achieve those standards leads to greater dissatisfaction. Subsequently, dissatisfaction leads to eating pathology (bulimia) through two pathways: negative affect and restrained eating (dieting).

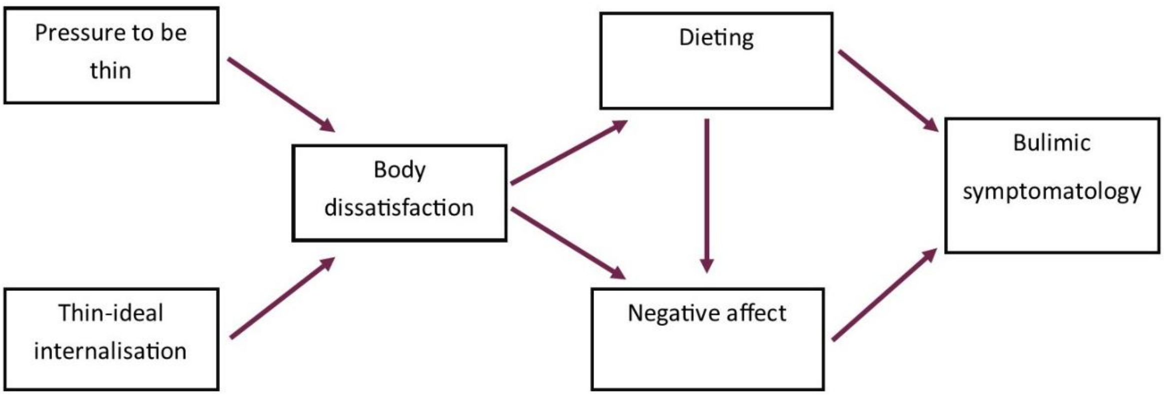

Figure 1.1*. Stice and Agras (1998) dual pathway model of bulimic pathology.*

The dual pathway model draws on the premise that women internalise the cultural messages (ideals, standards, stereotypes) about body and appearance and then build their self-esteem based on how their own appearance, shape and size compare to those standards. However, it needs to be specified that thin-ideal internalisation refers to *acceptance*, rather than merely *knowledge* of such societal standards, and *incorporation* of these beauty standards into their own self-concept, along with engagement in behaviours aimed at reducing the gap between one's actual appearance and the ideal (Thompson & Stice, 2001).

Stice (2001) then evaluated the dual pathway model in a prospective study of adolescent girls (n=231). Using random regression growth curve analysis, it was found that i) initial pressure to be thin and thin-ideal internalisation predicted subsequent increases in body dissatisfaction, (ii) initial body dissatisfaction predicted increases in dieting and negative affect, (iii) initial dieting and negative affect predicted increases in bulimic symptoms, supporting the model as illustrated in **Figure 1.1**.

While the original model set out to explain bulimic pathology, further work by Stice and colleagues extended the model to explain a broader range of eating pathologies (Stice & Shaw, 2002), see **Figure 1.2** below**.** Urvelyte and Perminas (2015) recently provided further support for this extension, as they found that this version of the dual pathway model applies not only to Bulimia but also to Anorexia (n = 348). Urvelyte and Perminas (2015) structural equation analyses confirmed initial pressure to be thin and thin-ideal internalisation predicted subsequent growth in body dissatisfaction, initial body dissatisfaction predicted growth in dieting and negative affect, and initial dieting and negative affect predicted growth in bulimia and anorexia symptoms.

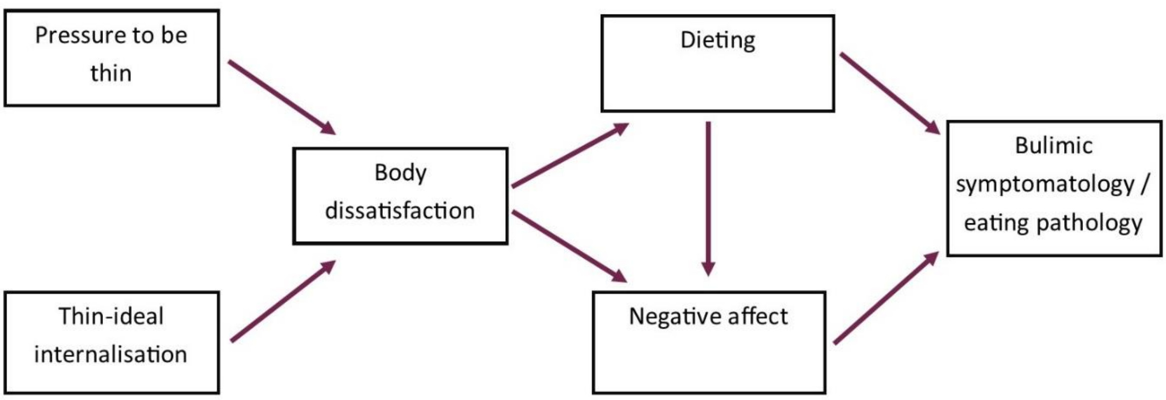

Figure 1.2. *The dual pathway model, extended to explain eating pathology overall.*

Stice and Shaw (2002) set out to further investigate the extended dual pathway model (**Figure 1.2**) and to review existing empirical findings of prospective and empirical studies regarding putative origins and consequences of body dissatisfaction. The review by Stice and Shaw (2002) found support for the model as presented in **Figure 1.2**, as well as support for including a number of additional risk factors, see **Figure 1.3** for revised conceptualisation of the dual pathway model. Elevated body mass was added as a new, biological risk factor for pressure to be thin, body dissatisfaction and dieting. Additionally, some additional connections between factors were added, e.g. in the original model body dissatisfaction was a risk factor for dieting and negative affect, it was also expanded as a risk factor for eating pathology overall, see **Figure 1.3** below.

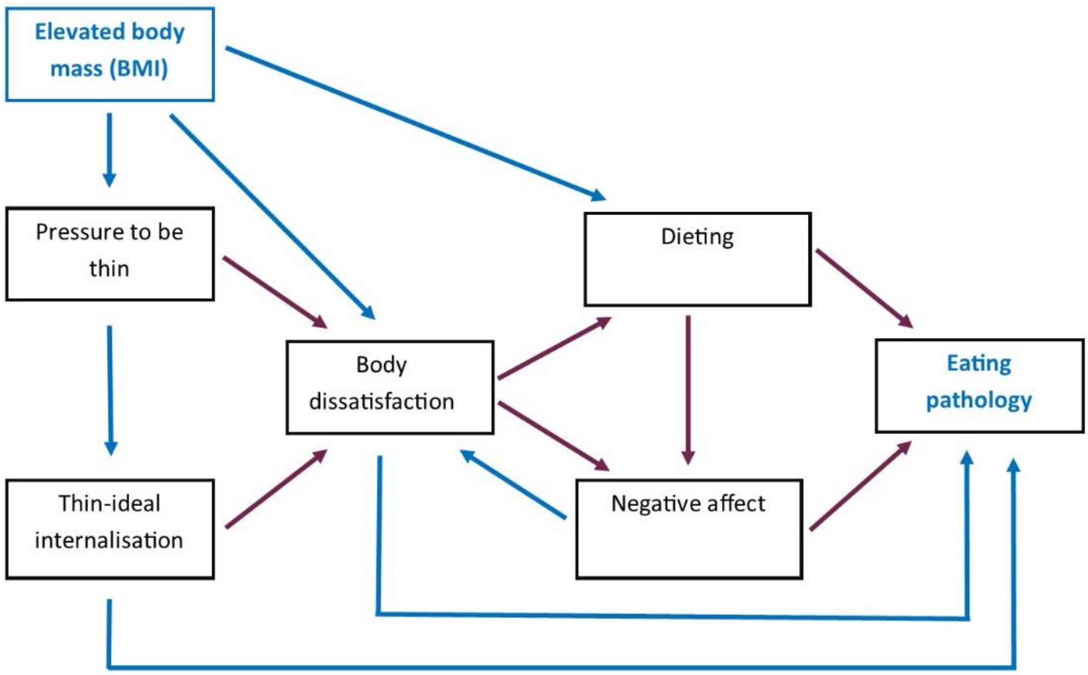

Figure 1.3. *Revised dual pathway model, based on Stice and Shaw's (2002) review of the dual pathway model for eating pathology. The added risk factors are emphasised in blue.*

A meta-analysis by Stice (2002) of 25 prospective and experimental studies carried out between 1980 and 2011 quantified the model as conceptualised by Stice and Shaw (2002). The review focused on studies that reported putative risk and maintenance factors of eating pathology and provided support for a number of risk factors, e.g. for elevated body mass as a risk factor for pressure to be thin, body dissatisfaction and dieting; body dissatisfaction was found to be a risk factor for dieting, negative affect and eating pathology; and negative affect, perfectionism, impulsivity and substance use were identified as risk factors for eating pathology. Perceived pressure to be thin and thin-ideal internalisation were found to be causal risk factors for body dissatisfaction, dieting, negative affect, and eating pathology; negative affect can be considered a causal risk factor for body dissatisfaction and caloric intake. However, prospective and experimental findings for dieting were not as clear, leading to a conclusion that dieting is not a risk factor as such, but rather attenuates over-eating tendencies. The reviewed model by Stice (2002) is presented in **Figure 1.4** below.

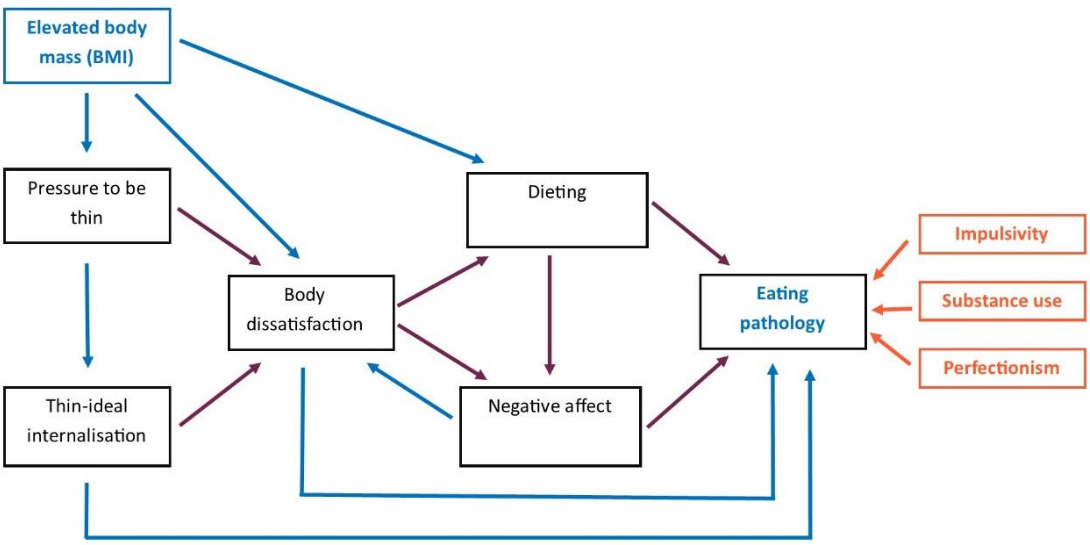

Figure 1.4. *Reviewed dual pathway model, based on Stice's (2002) meta-analysis of risk factors for eating pathology; new risk factors are emphasised in red.*

While a number of prospective and longitudinal studies have provided support for the dual-pathway model, as presented in **Figure 1.2** (Allen, Byrne, & Mclean, 2012; Cafri, Yamamiya, Brannick, & Thompson, 2006; Dakanalis et al., 2014; Maraldo, Zhou, Dowling, & Vander Wal, 2016; Ouwens, van Strien, van Leeuwe, & van der Staak, 2009;

Shepherd & Ricciardelli, 1998; Strien, Engels, Leeuwe, & Snoek, 2005; Stice & Bearman, 2001; Stice, Akutagawa, Gaggar, & Agras, 2000). Nevertheless, it continues to be re-visited and updated. One recent suggestion is to include fear of negative-evaluation (an apprehension about other's evaluation and expectation that others would evaluate one negatively) as a factor influencing thin-ideal internalisation; also, to include rumination and lack of self-compassion as a risk factor of negative affect and body dissatisfaction (Maraldo et al., 2016). This warrants further investigation as fear of negative evaluation is a rather new focus in this research area, and a relationship between fear of negative evaluation and weight/shape concerns has recently been found among both, adults and adolescents (DeBoer et al., 2013; Trompeter et al., 2018). Furthermore, van Strien et al. (2005) suggested extending the negative affect pathway by adding two additional variables: interceptive deficits and emotional eating. Their structural equation model analyses showed that while the data fitted the original model well, the extended model that included interceptive deficits and emotional eating fitted even better. Additionally, utilising structural equation modelling, Dakanalis et al. (2014) further confirmed that a model extended this way accounted for a greater proportion of variance than the original model (**Figure 1.2**).

Perhaps the most important criticism of the dual pathway model is the possibility of 'third variable' influence on the relations between body dissatisfaction, body mass, pressure to be thin, thin-ideal internalisation, dieting, negative affect and eating pathology. Although many studies have confirmed the dual pathway model, they have also extended the model, e.g. suggesting additional variables (e.g. Maraldo et al., 2016; Ouwens et al., 2009), bi-directional relationships (e.g. Dakanalis et al., 2014), therefore suggesting that the associations between the key factors are more complex than outlined in the original model. Furthermore, the dual model groups the different types of perceived pressure to be thin into one variable. This is important, because, as the next section will demonstrate, the pressure exerted by such influences can be very variable.

Nevertheless, this early socio-cultural model provided a framework explaining that people may absorb socio-cultural messages about the importance/desirability of thinness and develop body image disturbance, if certain pre-disposing factors are present, such as own body mass, peer and family pressures and weight-related teasing, low self-esteem and unstable self-concept. It has also led to development of a prevention intervention (Stice, Chase, Stormer, & Appel, 2001). The dual model provided foundations for further work and another socio-cultural model, The Tripartite Influence Model, which built on this foundation proposing social comparison as an important mediator between the socio-cultural messages and development of body image concerns and eating pathology.

The Tripartite Influence Model of eating pathology

Thompson, Heinberg, Altabe, and Tantleff-Dunn (1999) developed the tripartite influence model to incorporate the many risk and maintenance factors hypothesised to affect body image and eating disturbances. The tripartite influence model proposes that three formative influences (peer, family and media – hence the name "tripartite", Tiggemann, 2011) transfer body image ideals through two mediational mechanisms: thin-ideal internalisation and appearance comparison processes, which in turn lead to body dissatisfaction and then eating pathology. An additional aspect of the model includes a proposed directional link from the restricting component of eating disturbance to bulimia, and a link between bulimia and psychological functioning (Keery, van der Berg, & Thompson, 2004; Shroff & Thompson, 2006; van der Berg, Thompson, Obremski-Brandon, & Coovert, 2002); see **Figure 1.5** overleaf.

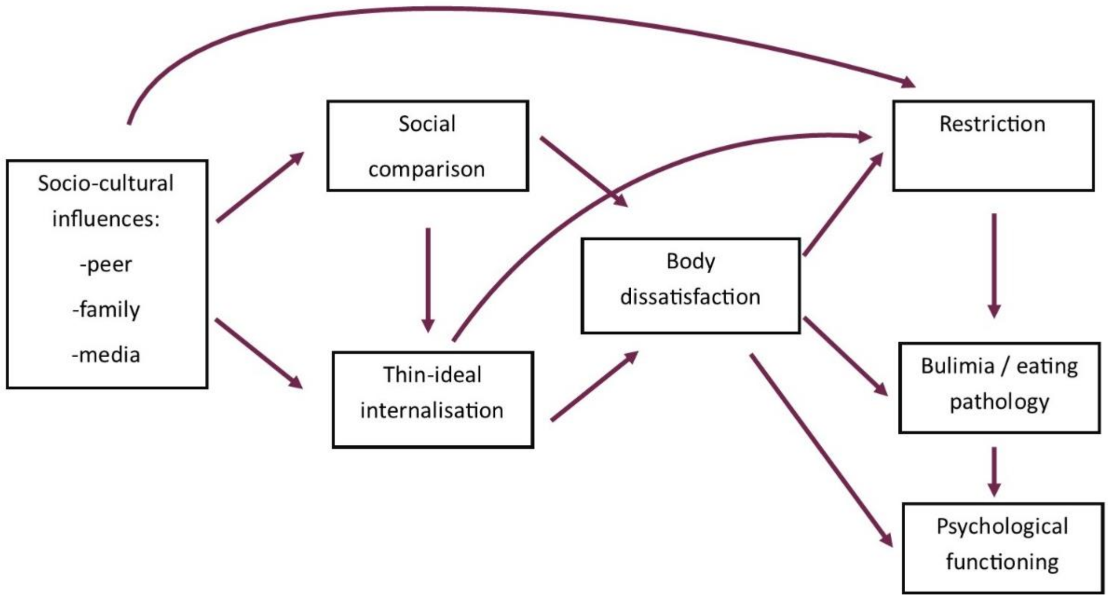

Figure 1.5. *The Tripartite influence model by Keery et al. (2004) demonstrating the core socio-cultural influence structures.*

Before reviewing the evidence supporting the tripartite model, the general concept of social comparison is discussed, as it is one of the crucial mechanisms mediating social ideals and their influence on body dissatisfaction and has not previously been described in this thesis.

Festinger's (1954) social comparison theory proposes that people are driven to gain accurate evaluations of themselves; individuals evaluate their own opinions and abilities by comparing themselves to others in order to reduce uncertainty and to learn how to define themselves. As such, according to the theory, people seek social comparisons to put their attributes into a context, define themselves and their self-concept, i.e. people evaluate themselves by identifying any discrepancies between themselves and others. Social comparison can be upward, i.e. comparing oneself with others whom one considers superior to oneself, or downward, i.e. comparing oneself with others who one considers to be inferior. In a week-long diary study (4 measurements per day) women with high body concerns were found to report to engage in upward body comparisons more often than body satisfied women. In both groups such upward comparisons were found to be associated with an increase in negative affect, body dissatisfaction and thoughts of exercising. Additionally, body dissatisfied women have engaged in more frequent upward comparisons and experienced increases in thoughts of dieting and negative affect (Leahey, Crother, & Mickleson, 2007). In the domain of self-esteem, upward comparisons in individuals who have low self-esteem have been found to lower their self-esteem even further, while downward comparisons improve self-esteem (Gibbons & Gerrard, 1989). This suggests that such comparisons may emphasise perceived inferiority or enhance superiority (Bailey & Ricciardelli, 2010). In the context of body image and eating pathology social comparisons include comparisons of how one's body looks, as well as comparisons of eating/diet and exercise behaviours to others. The effects of making appearance-focused social comparisons were examined in a meta-analysis examining 156 experimental and correlational studies; it was revealed that individuals who engage in comparing themselves to someone else on the basis of appearance experience greater levels of body dissatisfaction (Myers & Crowther, 2009).

Van den Berg et al. (2002) investigated the mediating role of appearance comparison on body image in the context of the tripartite influence model. Covariance structure modelling revealed that appearance-related social comparison indeed mediated the effects of family and media influences on body dissatisfaction, which in turn influenced restrictive and bulimic behaviours; whereas peer influences affected restrictive behaviour directly, indicating the significant role peer interactions play in restrictive behaviour (see **Figure 1.6** overleaf).

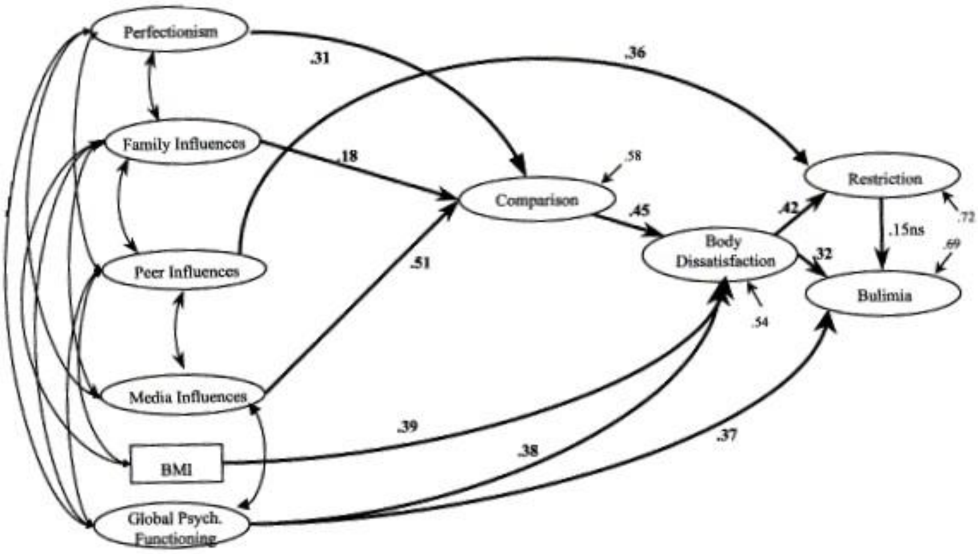

Figure 1.6. *The tripartite influence model by Van den Berg et al. (2002).*

Keery et al. (2004) provided further support for the model by evaluating it with three groups of adolescents aged: 11-12, 12-13, and 13-14 (n=325). Simple path analyses indicated that internalisation and appearance comparison fully mediated the relationship between parental influence and body dissatisfaction. Internalisation and comparison also partially mediated the relationship between peer influence and body dissatisfaction, and between media influence and body dissatisfaction. They further found that socio-cultural influences had not only indirect effects on restriction via internalisation, comparison and body dissatisfaction, but also a direct effect.

However, Keery et al. (2004), investigated the influences of media, parents and peers as one composite variable. Whereas Shroff and Thompson (2006a) not only replicated Keery et al.'s (2004) findings but also extended them by investigating each predictor separately. Shroff and Thompson (2006a) found that peer and media influences were more important than parental influences, suggesting a possible role of an individual's age, i.e. parental influences may be more pronounced in younger individuals, and as they age this is replaced by peer and media influences. Further work by Shroff and Thompson (2006b) elaborated these findings and suggested that adolescent girls particularly value the opinions of their peers in judging their appearance, and assign importance to their peers which likely impacts body satisfaction and likelihood of engaging in disturbed eating (Shroff & Thompson, 2006b). Results of mediation analyses suggested that internalisation, comparison and peer suppression of feelings may serve as mediators in the relationship between the composite peer influence variable and the criterion variables (Shroff & Thompson, 2006b).

The influence of peer relations appears to be a critical factor related to adolescent body image and eating pathology. Early research found that behaviours such as teasing, verbalised concerns about appearance, desire to be a part of a group and friends' dieting behaviours have led adolescents to diet (Paxton, Schutz, Wertheim, & Muir, 1997). Engaging in appearance conversations with friends has also been found to affect adolescent girls by directing their attention to their appearance, thereby reinforcing the value and importance of appearance and development of appearance-ideals (Jones, Vigfusdottir, & Lee, 2004). On the other hand, positive peer influences (e.g. being dissuaded from dieting or purging) have been shown to reduce dieting and purging behaviours, so it is possible that friends and peers may protect against such extreme behaviours (Wertheim et al., 1997). It is important to point out that there are gender differences in the extent to which internalisation and peer pressure contribute to body dissatisfaction in adolescent boys and girls; i.e. the stronger predictor of girls' body dissatisfaction was internalisation, while for boys it was pressure (Knauss, Paxton, & Alasker, 2007).

The importance of peer pressure should not distract from family influences as an important psycho-social factor in body image development. Family relationships and environment are early formative sources of social comparison and acceptable societal standards. Investigations in to the role of parental, typically maternal, influences on body image have revealed mechanisms such as direct encouragement to change shape/ weight (e.g. via weight teasing or even well-intentioned comments) and indirect encouragement of weight loss via maternal expressions of weight and diet concerns and comments (Neumark-Sztainer et al., 2010). While most studies find those maternal influences to promote body dissatisfaction, drive for thinness and dieting behaviour; maternal dieting has also been found to act as a buffer against negative effects of direct encouragement to lose weight (Hillard, Gondoli, Corning, & Morrissey, 2016).

Modern media depicts the thin-ideal body in a variety of ways, e.g. magazines, internet, social media, TV, music videos etc. The relationships between media as a risk factor for body dissatisfaction has been supported by extensive experimental, correlational and meta-analytic evidence (Boothroyd et al., 2016; Grabe, Hyde, & Ward, 2008; Groesz, Levine, & Murnen, 2001; Levine & Murnen, 2009; Tiggemann, 2003; Tiggemann & Slater, 2003). However, recently the influence of media has been contested, with suggestions that the effects of media may be small to negligible or limited to individuals already at risk for body dissatisfaction. A meta-analysis of 204 studies examining the effects of thin-ideal media messages on women revealed minimal effects for most women (Ferguson, 2013). The influence of those messages was greater for women with already developed body image concerns suggesting that women with pre-existing body dissatisfaction may be primed by media ideals. Further longitudinal research is needed, to examine the lasting, rather than immediate effects of media on body image and eating pathology.

Objectification theory

Negative body image and eating pathologies occur at higher rates in women than in male populations (Bulik et al., 2006; Hoek & Van Hoeken, 2003; Hudson, Hiripi, Pope Jr, & Kessler, 2007). Moreover, eating disorders can present differently between the genders, women seek to lose weight and desire to be thinner, and men split between losing weight and gaining muscle. (Dion et al., 2016; Drewnowski & Yee, 1987; Hoek & van Hoeken, 2003; McCabe & Ricciardelli, 2005; Valente et al., 2017). “Normative discontent” suggests that the cultural norms and female sex-role stereotypes and attitudes provide context for understanding preoccupation with thinness in society, especially in societies that stigmatise obesity (Rodin et al., 1984). The objectification theory, in particular, provides an approach that focuses on explaining women's preoccupation with appearance in the socio-cultural context that objectifies women and equates their worth with their appearance, and its effect on women's well-being, e.g. self-esteem, anxiety and eating pathology.

Objectification theory by Fredrickson and Roberts (1997) assumes that the society has a tendency to objectify the female body on a much larger scale than the male body; the theory attempts to understand the consequences of being female in such society (Slater & Tiggemann, 2002). Sexual objectification happens when a woman's body equates her worth to her external appearance i.e. the body is treated as an aesthetic object which represents the woman (Fredrickson & Roberts, 1997). Central to the theory is the suggestion that due to the socio-cultural pervasiveness of objectification, girls and women in such socio-cultural context internalise the objectification. In other words, women come to view and treat themselves as objects to be evaluated on the basis of their appearance – or to self-objectify, i.e. take a third person view of self. Objectification theory proposes that as the social norms and objectification of the female body are more common, women are disproportionally affected; e.g. it proposes that there is a cultural emphasis on how women's bodies look versus how men's bodies act (Murnen, 2011). As such females come to place greater value on how they look to others, rather than how they feel or what they can do (Calogero, 2012). This externalized view of the self is accompanied by self-consciousness characterised by vigilant monitoring of one's appearance, chronic body monitoring is referred to as self-surveillance (also referred to as body surveillance). Such acts of consistently measuring oneself against some internalised cultural standard link self-objectification and well-being, i.e. coming up short in such a comparison may result in body shame, body dissatisfaction and other negative feelings. For example, self-objectification has been associated with depression (Tiggemann & Kuring, 2004), appearance anxiety (Calogero, 2004) and eating disorders (Tiggemann & Slater, 2001).

Self-objectification and body surveillance are therefore proposed as a mechanism through which we can understand women's body image in contemporary Westernised societies. See **Figure 1.7** below for the objectification model.

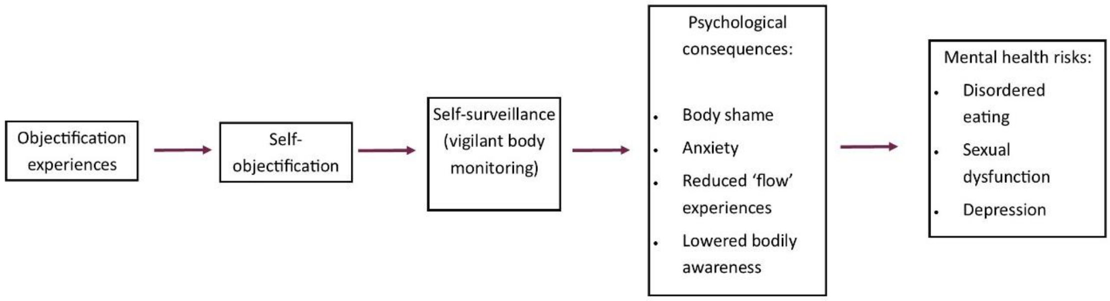

Figure 1.7. *Predictors of eating symptomatology in the context of objectification theory (Fredrickson & Roberts, 1997).*

Furthermore, the theory aims to explain several psychological or experiential consequences that occur at higher rates in the female population, such as body dissatisfaction and shame, appearance anxiety, reduced concentration of 'flow' experiences on mental and physical tasks, and diminished awareness of internal bodily states (Calogero, 2012; Paap & Gardner, 2011). For example, Lowery et al. (2005) administered five different body image scales to a sample of female (n=267) and male (n=156) college students. Women, compared to men, were found to report more body dissatisfaction, more body surveillance, greater body shame, and greater discrepancy between their ideal and actual body. These in turn may lead to a number of mental health risks that also occur at disproportionately higher rate among females such as depression, sexual dysfunctions and eating disorder symptoms (Johnson & Wardle, 2005; Paxton, Neumark-Sztainer, Hannan, & Eisenberg, 2006; Striegel-Moore et al., 2008).

Evidence from correlational, experimental and longitudinal studies of women in Westernised societies, such as North America, the UK and Australia has provided empirical support for this framework. For example, thin-ideal internalisation was found to predict self-objectification in a sample of women (n=209) in residential eating disorders treatment (Calogero, Davis, & Thompson, 2005). Self-objectification was also found to partially mediate the relationship between internalised appearance ideals and drive for thinness, while body shame partially mediated the relationship between self-objectification and drive for thinness (Calogero et al., 2005). Furthermore, Tylka and Hill (2004) used structural equation modelling to test the assumptions of objectification theory. Results indicated that pressure for thinness predicted unique variance in body shame, and that pressure for thinness, along with body surveillance, predicted 72% of the variance in body shame. Furthermore, women who self-objectify have been found to experience a range of inter- and intra-personal difficulties such as lower global self-esteem and more dysfunctional exercise attitudes and behaviour (Colagero, 2012; Munren, 2011).

The consequences of self-objectification illustrate the foundational nature of self-body relationship to body-related attitudes, behaviours and functions. When appearance becomes central to one's self-concept, women engage in a kind of psychological distancing; other qualities may be disregarded, and women spend more time and effort to attain societal body ideals (Calogero et al., 2005; Murnen, 2011; Stice & Shaw, 2002).

Moradi, Dirks, and Matteson (2005) re-evaluated the objectification model of eating disorder symptoms, as presented in **Figure 1.7**, and the role of socio-cultural standards. They found that internalisation of socio-cultural standards of beauty mediated the links of sexual objectification experiences to body surveillance, body shame and eating disorders symptoms. Additionally, body surveillance was an additional mediator of the link of reported sexual objectification experiences to body shame; and body shame mediated the links of internalisation and body surveillance to disordered eating. They extended the model and proposed an updated version which is presented in **Figure 1.8** overleaf.

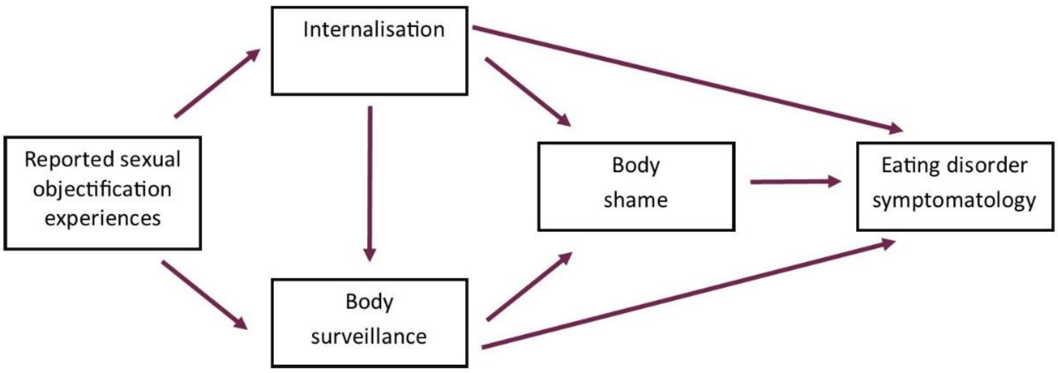

***Figure 1.8**. Elaborated model of predictors of eating symptomatology in the context of objectification theory (Moradi et al., 2005).*

As body surveillance emerged as a proposed mechanisms through which internalisation of body ideals lead to body dissatisfaction other researchers have attempted to incorporate it to the established socio-cultural models of disordered eating such as the tripartite model. The elaborated socio-cultural model by Fitzsimmons-Craft et al. (2014) attempts to extend the research on socio-cultural models of disordered eating. It proposes social comparison and body surveillance as the mediators of the relation between thin-ideal internalisation and body dissatisfaction; see **Figure 1.9** below.

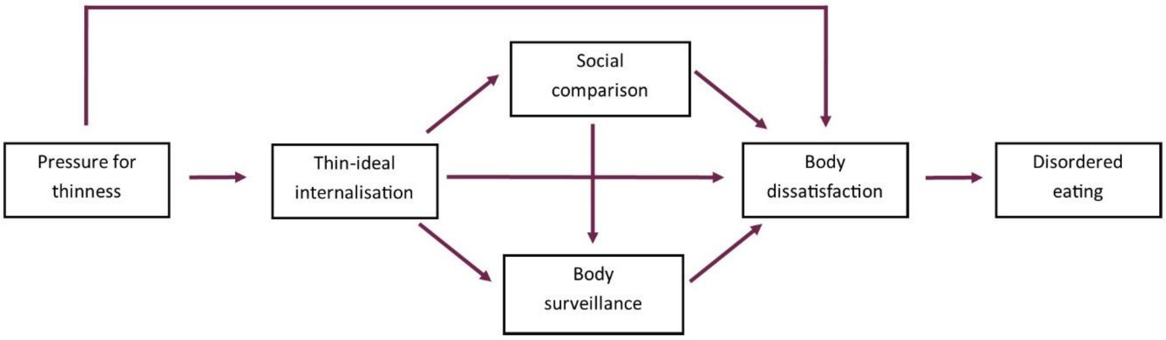

***Figure 1.9.** An elaborated socio-cultural model of disordered eating (Fitzsimmons-Craft et al., 2014).*

According to the model, in order to evaluate their bodies, women need to assess the discrepancy between the ideal body and their actual body. Social comparisons are used for such direct comparisons, while body surveillance is the process which starts off these evaluations. This model, however, is still to be thoroughly evaluated, especially as earlier findings by Fitzsimmons-Craft et al. (2012) are at odds with their later findings (Fitzsimmons-Craft et al., 2014). In short, when social comparison and body surveillance were included as mediators between thin-ideal internalisation and body dissatisfaction, the direct relationship between thin-ideal internalisation and body dissatisfaction became non-significant. This emphasises the importance of body comparison and social comparisons, as it may not be a given that internalisation of socio-cultural ideals is associated with body dissatisfaction.

1.3.2 Critique of the socio-cultural models

Socio-cultural theories provide an established framework for examining risk factors for body image disturbance and eating pathology; they highlight the role of cultural and interpersonal processes, implicating internalisation of appearance ideals and appearance-related pressures in the development of body image and eating pathology. There are, however, a number of criticisms.

Firstly, the terminology is often vague, without clear definitions as to how the various concepts differ, e.g. body shame and body dissatisfaction have been used almost interchangeably (e.g. Moradi et al., 2005), prior literature does not explain the dissimilarity of thin-ideal internalisation and self-objectification. Importantly, studies investigating the different models do not report on the uniqueness of the concepts. As such, there is a lack of focus on how the different components influence each other and how separable they truly are. In fact, it has been acknowledged that the contents of appearance comparison and internalisation of the thin ideal overlap, resulting in appearance comparison being excluded from analyses in the past (Huxley, Halliwell, & Clarke, 2014; Tylka, 2011). For example, Griffiths (2015) found that the items on the scale measuring upward comparison and internalisation of the thin ideal components were overlapping, which caused suppression effect problems in their statistical analysis, and led to the exclusion of the upward comparison component in model testing. Moreover, some reciprocal and bi-directional relationships have not been tested. For example, an episode of binge eating may lead to an increase in negative affect, while negative affect may be related to biased processing of body-related information and biased interpretation. Unfortunately, as the models are tested most authors conduct analyses that have the potential to confirm the model, i.e. only test the relationships between the status quo concepts and not exploring additional potential links beyond perhaps a new variable an author is attempting to introduce. Furthermore, there has been little theoretical work on factors that may mitigate the relationships between the model's variables, such as non-appearance related self-esteem which may render individuals more resilient to socio-cultural pressures.

Importantly, the effectiveness and efficacy of socio-cultural models has not sufficiently been investigated. Pennesi and Wade (2016) provide a great overview of the existing models in the context of application / intervention development, the authors bemoan the lack of quality investigations of the models. In particular they point out the lack of pregression beyond a model description and suggest a revision of the theoretical frameworks.

As such, socio-cultural approaches to eating pathology might also benefit from more systematic attempts to identify the most parsimonious models based on large datasets, by ensuring that the smallest number of latent variables consistent with the data are retained in, e.g. for structural equation modelling. Other possibilities include drawing inspiration from cognitive neuroscience, where dynamic causal modelling is used to identify functional networks in the brain that underpin particular behaviours. Here, Bayesian techniques are used to identify the winner(s) in a competition between models deliberately designed to include both variation in the number of nodes in a network, as well as the numbers and directionality of the connections between nodes (Friston, Harrison, & Penny, 2003).

Additionally, research has largely focused on the different components of the pathways as maintenance factors of the two eating disorders while not taking into account other risk and maintenance factors such as biological, personality and genetic predispositions. The understanding of the role genetics play in eating disorder development is increasing, with family, twin and adoption studies demonstrating that genetic factors contribute to the variane in liability to eating disorders (Shih & Woodside, 2016; Thornton, Mazzeo & Bulik, 2010; Bulik et al., 2006; Bulik, 2005). Importantly, it is also generally accepted that genes and environement interact to influence personality and behaviour (Mazzeo & Bulik, 2009). Research examining associations between personality traits and ED symptomatology in clinical samples has consistently concluded AN and BN to be characterised by perfectionism, obsessive-compulsiveness, neuroticism, negative emotionality, harm avoidance, low self-directedness, low cooperativeness and traits associsated with avoidant personality disorder (Cassin & von Ranson, 2005). There are also consistent differences that emerge between the two disorders.

Finally, the socio-cultural theories stress the importance of external pressures and lack specificity in terms of psychological mechanisms that may be crucial in development and maintenance of body image and eating pathology. Therefore, the question of why some women are more vulnerable remains. As such, the socio-cultural models may be too simplistic and not sufficient to explain how eating pathology develops.

1.3.3 Cognitive models

The following cognitive-social learning model of body image and eating pathology includes many concepts similar to those just presented above, such as the external influences of media and other people. The important development beyond social-cultural models is the inclusion of effects attributable to individual differences, information processing and behaviours. Therefore, the cognitive approach attempts to identify potential mechanisms involved in body image and pathology, and how/why certain feelings, attitudes and behaviours are maintained.

Cognitive-social learning model

The integrative cognitive-social learning model of body image by Cash (2012, 2008, 2002; see **Figure 1.10**) proposes that development of body image perception and attitudes are shaped by i) historical/developmental influences and ii) proximal influences, i.e. current life context and events, via an interplay of cognitive, emotional and behavioural processes.

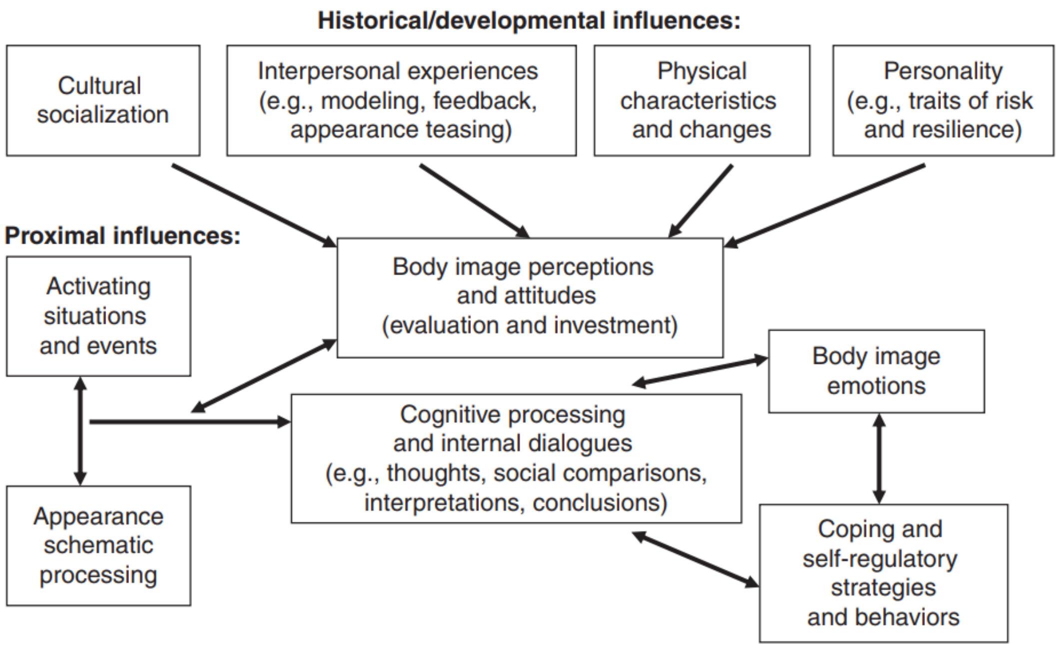

Figure 1.10. *The dimensions, determinants, and processes influencing body image (Cash, 2012).*

Historical factors refer to past events, experiences and cognitive-social learning that pre-dispose or influence how people come to think, feel, and act in relation to their body. Those influences include cultural socialisation, interpersonal experiences, physical characteristic and personality. Via experiences such as observational learning and conditioning one learns the meaning of physical appearance and one's body-related experiences during childhood and adolescence. In the context of cultural socialisation, media is yet again a relevant concept. Media communicates culturally-relevant information and guides evolution of beauty standards and appearance ideals, i.e. presents to the audience what is and what is not desirable. For example, fashion magazines and Playboy centrefold models have been shown to change in size and weight over the years, illustrating changing beauty standards (Sypeck, Gray, & Ahrens, 2004; Voracek & Fisher, 2002).

Shared experiences and interaction with others (including family, peers, partners and even strangers) are proposed as one source of historical influence, shaping the development of body image. Interactions with others can lead to feedback about one's appearance (e.g. praise, compliments, bullying or cat-calling), and may provide reinforcement of dieting success or spur on behavioural change (Garner & Bemis, 1982). Such interactions affect an individual on a personal level, which may reinforce or model cultural expectations in a manner that mass media does not (Cash, 2012). Those messages can be internalised, shaping one's body image and can be used for self-evaluation.

One's physical characteristics have been proposed as another important historical factor due to their potential to influence how others interact with an individual. For example, cat-calling, prejudice, discrimination and teasing are often based on physical characteristics (Brochu, Gawronski, & Esses, 2011; Frisén, Holmqvist, & Oscarsson, 2008; Liu, Lee, McLeod, & Choung, 2018; Molina et al., 2018; Puhl, Andreyeva, & Brownell, 2008). Over-weight and obese adolescents are more likely to be bullied, with their weight being the target of the bullying (Brixval, Rayce, Rasmussen, Holstein, & Due, 2012; van Geel, Vedder, & Tanilon, 2014). Experiences of weight discrimination have also been reported to be prevalent among adults with high BMI (BMI of 35+), for example in the form of name calling (Puhl et al., 2008).

Indeed, according to the cognitive-social learning model, any physical characteristic that may deviate from a standard of physical attractiveness can influence body image, self-consciousness and appearance concerns, e.g. differences due to body changes during puberty, pregnancy or ageing.

The last historical / developmental factor is personality (and other individual differences). A variety of personality traits have been investigated as predisposing and protective factors in the development of body image concerns. Poor self-esteem, negative emotionality, perfectionism, self-consciousness have all been found to contribute to the development of disturbed body image (Cash, 2002), whereas high self-esteem and positive and clear self-concept have been found to be protective (Cash, 2012; Vartanian & Dey, 2013).

Proximal influences relate to the operation of body image in every-day life and consist of precipitating and maintaining influences on body image experiences, including information processing and internal dialogues, body image emotions and self-regulatory actions (Cash, 2012); i.e. “activating” events and situations that can elicit emotions and behaviours, and how those are cognitively processed. These events and processes serve as precipitating or maintaining factors in one’s body image experiences in every-day life. In other words, people may have certain feelings about their appearance, but they do not constantly and continuously experience those emotions, but rather those emotions are reactions to specific triggering contexts. Therefore, as a result of past experiences certain situations represent classically conditioned stimuli, whereby people respond reflexively with particular thought patterns and emotions (Cash, 2012).

According to the cognitive-social learning model, people develop coping and self-regulatory processes that negatively re-enforce their body image. For example, avoidance of certain social situations or clothing and grooming to hide aspects of one’s body. Additionally, the cognitive-behavioural model of eating disorders proposes a number of cognitive biases related to attention, memory, and judgement that are a function if the obsession with thinness and/or fear of fatness (Williamson, Muller, Reas, & Thaw, 1999). Furthermore, the cognitive-behavioural model hypothesises that certain types of stimuli, such as body and eating-related stimuli, can activate the body self-schema in susceptible individuals (Williamson et al., 1999). The schema is described as a knowledge structure with the purpose of directing attention, perception and how information is processed (Vitousek & Hollon, 1990). Williamson et al. (1999) argued that schemata can just as easily serve a dysfunctional purpose if they bias judgement, thought and behaviour in a way that is self-destructive or maladaptive. Activation of such schemata may activate various cognitive biases such as attention bias, selective memory bias, and selective interpretational bias (Williamson, White, Tork-Crowe, & Stewart, 2004). Attention bias refers to differentially attending to stimuli pertaining to weight/shape and food/ eating, while selective interpretation occurs when an individual interprets incoming information in a biased manner consistent with the body schema. Due to memory bias, information related to weight/shape concerns is more easily encoded and accessed compared to other information. These processes are said to occur in an automatic fashion, outside of consciousness and guide a person's cognitive processing, resulting in interpretations consistent with negative body image and that result in negative emotion and a number of ED-related behaviours (Williamson et al., 2004).

Based on this review of socio-cultural and cognitive models, it is clear that the attitudinal component of body image is highly complex, with a multitude of interrelated concepts, risk and maintenance factors. In this thesis, we take a broad approach to measuring the attitudinal component of body image, and deliberately avoid the complexity of the models discussed above. Instead, because the focus of the research in this thesis is on the perceptual aspects of body image, our approach is a statistical one: we want a broad-brush statistical control for attitudinal effects. To do this, we estimate as much variance in the attitudinal component of body image as possible by administering a number of self-report tasks. Specifically, we have identified a number of attitudinal components, which we hope will capture the breadth of our participants' emotional state. Accordingly, we do not focus on more 'causal' parts of the models. For example, we do not measure thin-ideal internalisation or levels of self-objectification. However, we do measure the resulting body dis/satisfaction, indicators of negative affect such as self-esteem and tendency towards depression, as well as indicators of eating pathology: dietary restraint, eating attitudes, and shape and weight concerns. We note that in a previous study, Cornelissen et al. (2017; 2015) demonstrated high levels of inter-correlations among such variables, to the extent that they were justified in using factor analysis to extract one, sometimes two, psychometric latent variables in order to index the attitudinal aspects of body image distortion.

1.4 Components of body image: Perceptual

The perceptual component of body image is the picture of our own body that we form in our mind: 'what size/shape I think I am' (Slade, 1988). Body image distortion (BID) refers to the difference between a person's actual body size and their judgment about their body, i.e. the size/shape they believe themselves to have. This may be inaccurate or unrealistic, e.g. believing oneself larger than is objectively true. Typically, patients with anorexia nervosa judge themselves as '(too) fat' or 'normal' even when dangerously underweight. Currently, body image distortion is considered to be a cardinal feature of Anorexia Nervosa, and is included as one of the diagnostic criteria of the disorder, i.e. "*a disturbance in the way one's body weight or shape is experienced*" (DSM-5, 2013), as presented in section 1.2.1. This is different to body dysmorphia, which is classified among obsessive-compulsive and related disorders, as a "*preoccupation with one or more non-existent or slight defects or flaws in their physical appearance*" (DSM-5, 2013).

In the following sections, we introduce the variety of methods that have been used to measure perceptual body image, and how this may differ in individuals with eating disorders compared to healthy controls.

1.4.1 *Measuring perceptual body image*

Measurement of the perceptual component of body image has arguably been more challenging than the measurement of the attitudinal component. This section introduces the complexity and variety of different depictive and metric methods, which also vary according to whether the whole body or body parts are estimated.

An example of a metric body part estimation method involves the use of kinaesthetic or moveable callipers, where participants adjust the distance between two moveable indicators to match the perceived width of a body parts (Gleghorn, Penner, Powers, & Schulman, 1987; Reitman & Cleveland, 1964). Variants of this method have involved participants adjusting light beams or points of light to indicate the width of body parts (Slade & Russell, 1973; Thompson & Spana, 1988). However, as reviewed by Farrel, Lee, and Shafran (2005), estimating one's size by adjusting the horizontal separation of two points assesses many more skills other than size perception, such as memory, visualisation and mental representation. As such, it is a method poor in construct validity. It also lacks ecological validity as it is unlike the typical ways one can estimate body shape and size, such as looking down at one's body, looking in a mirror or looking at photographs. The image marking procedure requires participants to point out perceived body sites on a sheet of paper attached to a wall, while blindfolded (Askevold, 1975; Fernández-Aranda, Dahme, & Meermann, 1999; Fuentes, Longo, and Haggard, 2013). This method has met with similar criticism of poor construct and ecological validity (Farrell et al., 2005).

An example of an early depictive whole body assessment technique is the body-distorting mirror, an adjustable mirror which distorts the size of the whole body, both horizontally and vertically (Traub & Orbach, 1964). Simple figural stimuli have also been used as a depictive method where a participant chooses a line drawing that they think best represents of their body shape/size (Bell, Kirkpatrick, & Rinn, 1986; Stunkard, Sorensen, & Schulsinger, 1983). These scales consist of line drawings of the human body that range in size from very underweight to obese as illustrated in **Figure 1.11.**

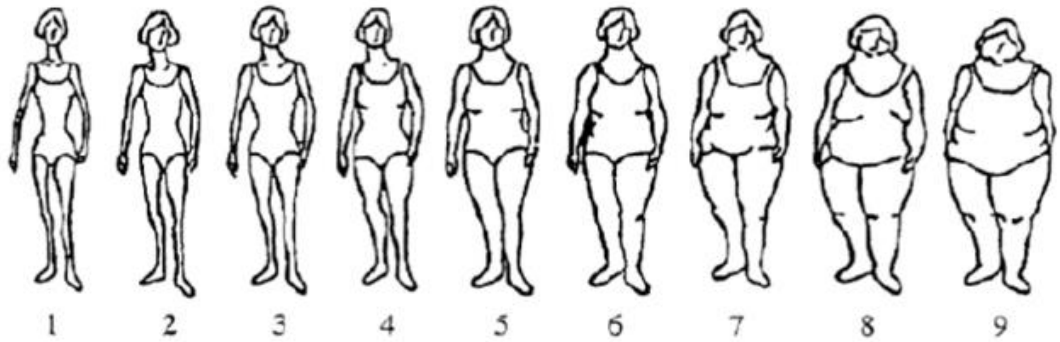

***Figure 1.11**. Example of silhouette stimuli (Stunkard et al., 1983).*

Line drawings and silhouettes, once popular in the 1980s and 1990s, suffer from a number of methodological deficiencies, such as scale coarseness, presentation difficulties (i.e. always presenting in ascending order which makes it easy for participants to remember which one they chose in case of repeat measurement), restriction of range and non-linear scaling (Gardner, Friedman, & Jackson, 1998). They also lack validated psychometric properties and have largely fallen out of favour (Gardner & Brown, 2010). Furthermore, they have been argued to measure the attitudinal component (i.e. body dissatisfaction) and to not actually provide any measure of perceptual size distortion (Gardner & Boice, 2004; Gardner & Brown, 2010).

Most image distortion techniques vary apparent body size by expanding or contracting an image of a body horizontally, to simulate changes in body adiposity. Glucksman and Hirsch (1969) pioneered a technique of photograph distortion; the photograph of a person's body was projected through an anamorphic lens. The participants were tasked with adjusting the width of the stimuli to match their perceived body size (Garner, Garfinkel, Stancer, & Moldofsky, 1976). It was argued that using this technique was expensive, and an alternative, essentially identical technique was developed where a horizontally distortable video feed of the participant was presented on a monitor (Allebeck, Hallberg, & Espmark, 1976). Many others have used this so-called Video Distortion Technique (VDT), establishing it as a standard (Fernández-

Aranda et al., 1999; Freeman, Thomas, Solyom, & Hunter, 1984; Smeets, Ingleby, Hoek, & Panhuysen, 1999).

To improve the ecological validity of the technique, in this case to make the image more akin to looking in the mirror, the stimuli have been projected life-sized in a number of studies (Gardner & Bokenkamp, 1996; Probst, Vandereycken, & Van Coppenolle, 1995; Shafran & Fairburn, 2002).

There is, however, a major problem with the whole-body Video Distortion Technique. Manipulations of the image in the horizontal axis (compression and expansion), while capturing many essential features of changing adiposity, nevertheless completely fail to capture other structural changes in the abdomen, chest and limbs, while also introducing distortions that are not realistic (Cornelissen, Tovée, & Bateson, 2009; Smith, Tovée, Hancock, Cox, & Cornelissen, 2007). As illustrated in **Figure 1.12** overleaf (Cornelissen et al., 2015) applying the VDT to an image of a woman with mid-range BMI expands the dimensions of the skeleton, e.g. hips and shoulders, which should not change when adiposity increases. Additionally, shoulders and hips become narrower when the image is compressed, when simulating loss of adiposity. In reality, lower adiposity would make bones in these areas more prominent. Lastly, the width of the gap between the thighs should reduce with increasing adiposity, yet, with the VDT the gap increases.

Cornelissen et al. (2015) describe how the body width changes implemented by the VDT amount to a ‘multiplicative’ model of body weight change, i.e. the horizontal width of the stimulus image is scaled multiplicatively. However, this model does not capture the relationship between waist-hip ratio and BMI accurately, which, as Cornelissen et al. (2009) have shown, should follow a monotonically increasing, decelerating relationship.

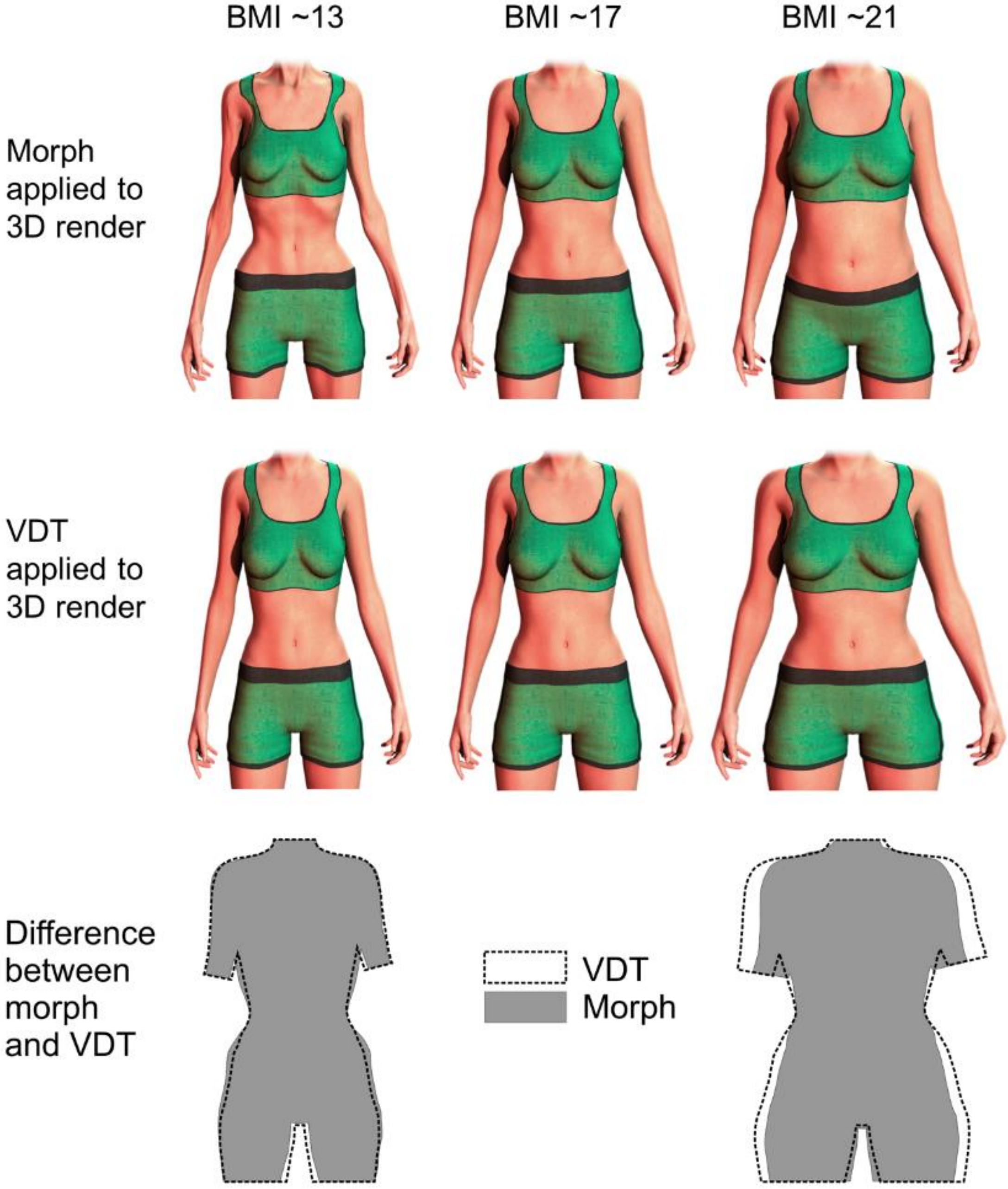

***Figure 1.12**. Comparison of VDT and CGI*

The top row shows three CGI stimuli of Cornelissen et al. (2015) representative of BMI 13, 17 and 21. The images in the middle row have had the video distortion technique (VDT) applied to the central image in the top row. To facilitate comparison between techniques, the waist widths of the compressed and expanded images in the middle row correspond to those of BMI 13 and 21 images from the top row, respectively. The bottom row shows a direct comparison between the outlines of the images produced by these manipulations. The CGI image in solid grey and VDT is the dotted line.

Poor face validity of VDT stimuli was noted by Smeets et al. (1999) who reported three anorexic participants with BMI below 15, and who, in this study, complained that horizontally expanded images did not look natural: they still looked emaciated and bony, but not “fleshier”. Smeets et al. (1999) reported that for those three participants size estimation was easy and their scores were very accurate.

To address such problems, recent research has focused on the creation of high definition, photo-realistic CGI (computer generated imagery) models that accurately reflect body mass index (Cornelissen, Bester, Cairns, Tovée, & Cornelissen 2015; Mölbert et al., 2017b; Piryankova et al., 2014). For example, the stimuli developed by Cornelissen et al. (2015) successfully capture BMI-dependent body shape changes in a realistic fashion. Moreover, because the images are calibrated for BMI, body image distortion can be expressed directly as the difference in participants’ actual BMI versus the BMI of the image that best represents the body size they believe they have.

Cornelissen et al. (2017, 2016, 2015) have used CGI stimuli, along with psychophysical and behavioural methods in their recent research investigating body image distortion. However, in these studies, participants always see BMI dependent shape variation of the same, standard model. The use of a standard model ignores individual variation in the underlying body shape of different observers: not every woman has an hour-glass figure. Standardised stimuli may therefore be a good fit for some observers, but this is not universal. Moreover, not only must participants cognitively map their own body image onto that of the stimulus (Stewart et al., 2012), but the extent of this shift will be variable depending on how closely the underlying body shape of the stimulus model matches that of the observer; and this represents an uncontrolled source of variability in such tasks.

In general, the inconsistent methods and lack of consensus over how best to measure perceptual body image are particularly concerning in clinical settings. To quote Cash and Smolak (2011): ‘*the scientific value of research on body image can only be as good as the tools employed in the measurement of this multidimensional construct*.’ It is therefore imperative to further develop more precise and accurate measurement tools to advance our understanding of the role of perceptual processes in body image. To this end, in this thesis, we have followed the same strategy as e.g. Cornelissen et al., and Mölbert et al., by making use of 3D stimuli in combination with robust psychophysical measurement methods. Furthermore, in Chapter 5, we pursue solutions to the problem created by variation in individual body structures leading to variable demands on cognitive mapping, by creating stimuli that are tailored to individual's body shape.

1.4.2 Body size estimation in eating disorders

In the 1960s Bruch published extensively on the subject of Anorexia Nervosa (AN). She described body image disturbance of *'delusional proportions*', disturbance in perception, and disturbance in attitude towards own body and self-concept, among other characteristics of the disorder. She also argued that the pathology of AN was not based on the severity of malnutrition as such, but rather the distortion of body image associated with it. Bruch (1962) further emphasised the importance of evaluating the disturbance in body image, not only as a diagnostic criterion, but also in appraising treatment progress. She argued that *'without a corrective change in the body image, the improvement is apt to be only a temporary remission'* (p. 189). Currently, there is a consensus that improvements in body image are crucial for eating disorder prevention, treatment, and recovery (Cash, 2008). We review key literature on the treatment of AN in section 1.7 and present empirical evidence in support of a new perceptual intervention for body image distortion in Chapter 7.

Most studies find that participants with eating disorders over-estimate their own body size in comparison to controls (Cash & Deagle, 1997; Fernández-Aranda et al., 1999; Gardner & Bokenkamp, 1996; Hagman et al., 2014; Hamilton & Waller, 1993; Mohr, Zimmermann, Röder, & Lenz, 2010; Probst, Vandereycken, Van Coppenolle, & Pieters, 1998, 1995; Roy & Forest, 2007; Slade & Russell, 1973; Taylor & Cooper, 1986; Tovée, Benson, Emery, Mason, & Cohen-Tovée, 2010). However, there is no clear consensus as a number of studies have not replicated this result (Fernández-Aranda et al., 1999; Fernández, Probst, Meermann, & Vandereycken, 1994; Mölbert et al., 2017b; Probst, Vandereycken, Van Coppenolle, & Pieters, 1995).

There have been a number of meta-analyses of body size estimation in eating disorders published. One of the earliest by Cash and Brown (1987) demonstrated the inconsistency of findings across studies. In those studies, utilising body part methods, anorexics were found to over-estimate to a greater extent than controls in 4 studies, while no difference was found in 6 studies; bulimics showed greater overestimation in 2 studies and no difference was found in further 2 studies. However, in those studies using the distorting image methods, anorexics over-estimated more than controls in 3 studies and, a further 3 found no difference. Bulimics showed greater overestimation than controls in 2 studies. Of the studies reporting no differences, over-estimation was found not to be unique to patients with eating disorders. It was concluded that inconsistencies in findings were likely due to the variety of methods used. Indeed, a later review of 33 size estimation studies by Smeets, Smit, Panhuysen, and Ingleby (1997) specifically investigated the extent to which methodological differences influenced study outcomes. These authors found a general over-estimation of body size among anorexic patients compared to controls using both, whole body and body part methods. However, the whole-body methods showed greater consistency in demonstrating over-estimation. Another meta-analysis by Cash and Deagle (1997) showed the whole-body methods to produce larger effect sizes than the body part methods. They also found anorexics and bulimics did not differ from one another relative to controls. Cash and Deagle (1997) concluded that eating disordered women have greater perceptual body size distortion than healthy controls.

A subsequent review by Skrzypek, Wehmeier, and Remschmidt (2001) of body size estimation studies in anorexia found that while five studies reported over-estimation another 4 were unable to replicate those results. All of the reviewed studies used either the video distortion technique (VDT) or figural scales. A later review of studies conducted between 1973 and 2002 by Farrell et al. (2005) found that eating disordered participants over-estimated their size in comparison to controls in 44 of the studies. Additionally, 16 studies either found no differences between groups or found all groups to be accurate. Most of these studies again used the VDT and figural drawing scales, and few other techniques such as the image marking procedure. The authors again concluded that the discrepancies between the findings may be attributable to the wide variety of assessment techniques.

Probably the most recent review by Gardner and Brown (2014) investigated nine studies conducted between 2002-2013 and concluded that in all studies that included a healthy control group, AN patients over-estimated their whole body size more than the healthy controls did; the difference was significant in all but two studies. Gardner and Brown (2014) conclude that the improved consensus of the more contemporary findings may be attributed to improvements in the measurement methods.

1.4.3 Non-body size estimations in eating disordered participants and controls

A key question is whether body image distortion might be caused by a generalised sensory / perceptual deficit (Cash & Deagle, 1997; Madsen, Bohon, & Feusner, 2013). A number of studies have focused on investigating purely visual disturbance in anorexia in the attempt to understand/explain abnormal body size estimation. For example, Slade and Russell (1973) have shown that while their sample of anorexic participants over-estimated their body size in comparison to controls, they were accurate in size estimation of physical objects (wooden blocks); additionally, the performance on the two tasks was not correlated. Similarly, Garner et al. (1976) found that anorexic participants were accurate in estimating the size of another control object, a vase (widest and narrowest point). Anorexic participants were also found to be accurate in estimating the width of a standard female model (face, chest, waist and hips), as well as female-shaped dummies (Meermann, 1983; Smeets et al., 1999).

It has been shown that as a result of restriction / starvation, anorexic patients may suffer physical changes/damage to their visual systems, such as decreases in the thickness of the macular and retinal nerve fibre layer, conjunctival squamous metaplasia, as well as decreases in the electrical activity of the macula. However, these anatomical and physiological changes were not associated with impaired visual function (Caire-Estévez, Pons-Vásquez, Gallego-Pinanzo, & Pinanzo-Durán, 2012; Moschos et al., 2011). Consequently, it is thought to be unlikely that body size over-estimation results from disturbances in low-level vision alone. However, as Madsen et al. (2013) write: *"conscious perception is a complex phenomenon that relies on multiple visual processing systems in the brain, along with tightly linked cognitive and emotional processes that contribute to subjective perceptual experience"* (p. 1484). Their review of ophthalmological, neuropsychological, visual and functional studies was summarised as inconclusive due too many discrepancies across studies and difficulties in determining whether observed differences in visual processing are related to weight, nutrition or other symptoms (Madsen et al., 2013).

1.4.4 Investigating body image with classical psychophysics

Slade and Russel (1973) wrote: *"… the term 'perceptual distortion' has been freely used to refer to the systematic size estimation error observed. However, the error tendency might equally reflect a judgemental as opposed to a purely perceptual process"* (p. 196). Slade and Russell (1973) suggested that size estimation tasks measure visual memory of one's body and its proportions, which is likely to be influenced in turn by a person's attitude to their body. This returns us to the central idea of body image, that there are at least two components: perceptual and attitudinal, and it begs the question to what extent are they really independent of each other? Or, is performance on what purports to be a perceptual size estimation ask, really a proxy estimation of body attitude?

Two related possibilities were proposed by Smeets et al. (1999). The first, a bottom-up approach: "*a disturbance of body image implies a disturbance of visual perception. The body is imaged as fatter because it was originally perceived as fatter […] imagery is equivalent to retrieving a previously perceived visual pattern from visual memory*" (p. 466). The second explanation was a top-down approach: "*disturbance occurs at the state of imagery. Because she thinks she is fat, the individual with AN, constructs a visual image of herself as fat*" (Smeets et al., 1999, p. 466). Furthermore, Smeets et al. (1999) go on to explain that they consider such visual imagery to be reconstructed from memory, a process in which associated thoughts (or feelings) may affect the resulting image. Smeets et al. (1999) clarified that the disturbances may originate at the level of *reconstruction* of the visual pattern during imagery, rather than at the level of *registration*.

In principle, Signal Detection Theory (SDT) (Gescheider, 1997; Green & Swets, 1966; Tanner & Swets, 1954) offers a way to distinguish between the possibilities proposed by Smeets et al. (1999). According to SDT, any judgements or decisions made by an observer are driven by two mechanisms: (i) signal strength as detected by the sensory system, and (ii) the observer's internal criterion, or bias (C) that they have to respond in a particular way (Stanislaw & Thodorov, 1999). During performance on an appropriately structured task, an observer's responses can be categorised into hits (stimulus: present; response: 'stimulus present'), false alarms (stimulus: absent; response: 'stimulus present'), misses (stimulus: present; response 'stimulus absent') and correct rejections (stimulus: absent; response: 'stimulus absent'). From the hit and false alarm rates, an observer's performance can be described in terms of pure sensitivity, i.e. how difficult it is to detect that a target stimulus is present in background noise. Sensitivity is indexed by D-prime (*d*'), and it corresponds to the difference between the mean of the signal plus noise distribution and the mean of the noise distribution, divided by the standard deviation of the noise distribution (Gescheider, 1997). An observer's criterion, or bias, can also be calculated, which refers to the tendency for a particular response to be more probable than another. Critically, this bias measure is independent of sensitivity.

With respect to the kinds of debate raised by Smeets et al. (1999), we can in principle, apply signal detection theory by equating d-prime with estimates of perceptual body image, and bias with estimates of attitudinal body image. Accordingly, Smeets et al. (1999) employed the method of constant stimuli in combination with the VDT to ask AN participants and controls to judge pairs of images, presented side by side. One image was a picture of the participant (i.e. the standard, or reference stimulus) and the other was a picture of the participant that had been compressed/expanded in the horizontal dimension, to represent being thinner, equal in size or bigger than the standard. On each trial, participants were asked if the two images were same or different. Using signal detection theory, Smeets et al. (1999) found no difference in sensitivity between the AN and control participants. The authors also found that both groups of participants were biased towards reporting thinness (i.e. they used a lower criterion), and that this effect was significantly stronger in the AN group than the controls. Smeets et al. (1999) therefore concluded that while AN participants were able to detect small changes in body size just as well as controls, nevertheless they had a stronger tendency towards reporting the stimulus as thinner.

A similar discrimination study had been reported earlier by Gardner and Moncrieff (1988) in which participants were asked to detect the presence of image distortion. These authors also found no differences in sensitivity (indexed by d-prime) between AN and control participants, but they did find that the AN group had a stronger bias for reporting the presence of image distortion. We would argue however that, while the results from both studies might be perfectly valid in themselves, they do not address the central question: what body size did their participants *believe themselves to have?* It appears from the reports that participants could solve the experimental tasks simply by judging whether the images set before them were the same or different/distorted or not, and there seems to have been no requirement for participants to have related that decision to their own internal representation of their body shape/size: as if the person in the stimulus images could have been anybody. In fact, we suggest that it may turn out to be impossible to construct a task appropriate for signal detection analysis where the question is: “what size do I believe I am?”. To do this, one would need to be able to manipulate the signal of interest in a predictable way (e.g. an AN participants’ belief), for example by distorting it by known amounts. Almost by definition this seems impossible, because both the signal and the observer bias “reside” in the mind of the observer and cannot be accessed directly.

Given this apparently irreconcilable difficulty with applying signal detection theory to the analysis of self-estimates of body size, researchers have had to rely on classical psychophysical methods to measure two components of participants’ judgements of body size: (i) the point of subjective equality (PSE) and (ii) the difference limen (DL). The PSE corresponds to *the body shape/size the participant believes themselves to have*, it is the participant’s estimate of their body size. The DL corresponds to *how sensitive* a participant is to differences in body size when comparing pairs of stimulus images. It is the amount of change necessary for the participant to detect the difference 50% of the time. The problem with these methods is that both PSE and DL are influenced by the subjective states of the observer – for example their expectancies about the stimuli (Gescheider, 1997) – and are therefore both prone to bias. Nevertheless, it is possible to see dissociations between the two measures, which are useful and interpretable.

Gardner, Jones, and Bokenkamp (1995) used three methods of size estimation: the method of adjustment, signal detection and method of constant stimuli. They found a significant correlation between PSE from the method of constant stimuli and bias from the signal detection approach. They also found a correlation between DL and *d*', although it was not significant. This is reassuring because it suggests that in situations where signal detection theory can be applied, there appears to be a degree of cross-validation between techniques for body size estimation.

With respect to participants with AN, Gardner and Bokenkamp (1996) used the video distorting technique (VDT) to measure the smallest horizontal distortion to body width that 35 AN and BN female participants and 19 healthy female controls could detect. Importantly, the patient groups conformed to the typical DSM IV definitions used for such studies and had very low BMIs (< ~18). The authors used adaptive probit estimation (Watt & Andrews, 1981) in combination with the method of constant stimuli in order to estimate both the DL and PSE for each participant. They found significantly larger PSEs on average for AN participants than for controls, but no difference between the groups for DL. These results are entirely consistent with participants with AN believing themselves to be larger than they actually are, even though they were just as sensitive in the psychophysical task as controls. The fact that these results to some extent mirror Smeets et al. (1999) suggests that choosing a classical psychophysics approach over signal detection may not be such a poor compromise.

The findings of Gardner and Bokenkamp (1996) were based on a typical anorexic sample, presenting with low BMIs. More recently other researchers have revealed a rather more complex picture. Cornelissen, Johns, and Tovée (2013) came to a different conclusion following a re-analysis of Tovée et al. (2003) as they found that the inaccuracies in body size estimation could largely be explained by a known perceptual error in magnitude estimation called contraction bias (Poulton, 1989). Contraction bias postulates that everyone holds a reference magnitude for familiar stimuli, magnitudes larger than the reference are under-estimated, while magnitudes smaller than the reference are over-estimated (Poulton, 1989). Here, such a reference would be the human body. **Figure 1.13**A overleaf shows a schematic representation of the results from Cornelissen et al. (2015); the relationship between estimated BMI and actual BMI appeared to be exactly the same for participants with anorexia and controls, i.e. there were no differences in the pattern of contraction bias between the two groups. Women with anorexia and controls estimated their own size using an interactive programme. The performance of the control participants ranged between BMI of 14.7 and 36.8, and is indicated by the cross-hatched area, whereas the grey area represents the performance of anorexic participants, ranging between BMI of 11.5 and 18.4. The dotted black line represents the line of equality, i.e. perfect accuracy. The solid black line represents the regression of estimated BMI on actual BMI and has the same slope and intercept for women with anorexia and controls. The thick dashed line represents the increase in intercept for the regression of estimated BMI on actual BMI as psychological concern about body shape and weight increase. The contraction bias explanation predicts for both groups, that the accuracy of their body size estimation will be driven by the BMI of the participants.

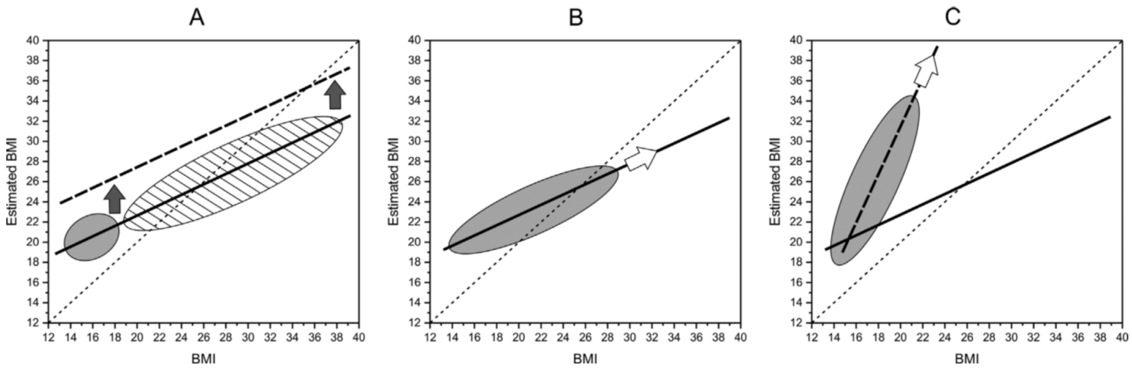

Figure 1.13 *Graph A shows a schematic representation of the results from Cornelissen et al. (2015); graph B shows the pattern of body size estimation predicted by the contraction bias model in women with anorexia, or recovering from anorexia (i.e. eating disordered group with a wider BMI range); graph C shows the pattern of body size over-estimation predicted by increasing psychological concerns, rather than contraction bias.*

However, as argued by Cornelissen et al. (2015) the participants in Tovée et al. (2003) presented with a rather narrow range of BMIs (11.5 - 18.4, i.e. only across 6.9 BMI units) and most of the variation in BMI was accounted by the responses of the controls who ranged in BMI between 14.7 and 36.8, i.e. a range of 22.1 BMI units. Should the range of BMIs in the anorexic group be increased (e.g. by including individuals in recovery), the assumption is that then the responses of anorexic participants would follow the same pattern as the control participants, as illustrated in panel B of **Figure**

1.13. The white arrows show how the regression of estimated BMI on actual BMI in these women should track up along the same regression line as in panel A in **Figure 1.13** when BMI increases (Cornelissen et al., 2013). In other words, the model predicts that as BMI increases in women with anorexia, so body size over-estimation should *decrease*. Cornelissen et al. (2015) also proposed an alternative; it is possible that psychological factors represent a stronger driving force behind body size over-estimation in women with anorexia, than they do for controls. An individual's body size is strongly correlated with body dissatisfaction (Stice & Shaw, 2002). During recovery from anorexia, body size concerns would likely rise in parallel to weight gain (weight restoration). Therefore, Cornelissen et al. (2015) proposed an alternative possibility that as anorexic participants' weight increases there is rapid rise in the degree of body size over-estimation that reflects their accelerated concerns about body shape and weight as illustrated in the C panel in **Figure 1.13**. The white arrow in the figure shows how the regression of estimated BMI on BMI for women with anorexia should follow the trajectory of the thick dashed black line.

Cornelissen et al. (2015) investigated a sample of 42 women who previously had been diagnosed with anorexia (referred to as anorexia spectrum disorder, ANSD) and 100 healthy controls. They found that control participants of low BMI over-estimated their size, whereas controls of high BMI under-estimated, as predicted by contraction bias. The results in the ANSD group, however, were very different and did not follow contraction bias. While low BMI ANSD participants were extremely accurate at estimating their size and very sensitive to changes in body size (as indexed by DL) as the BMI rose in the ANSD group a rapid increase in over-estimation, concurrent with rapid decline in sensitivity to size change was found (Cornelissen et al., 2015); see **Figure 1.14** overleaf.

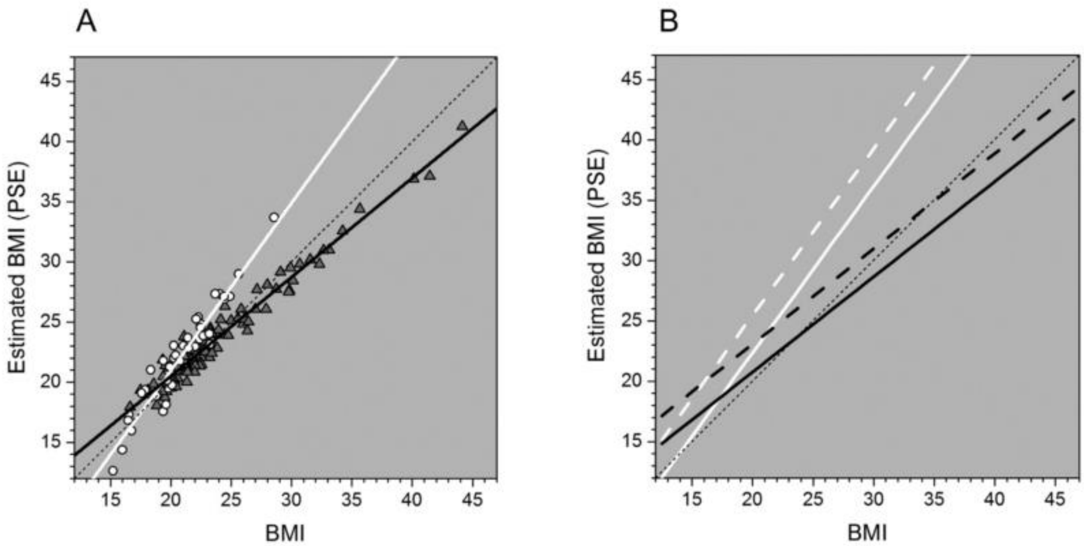

Figure 1.14. *Results of Cornelissen et al. (2015); women with history of AN (in white) and healthy controls (in black). A) Shows the relationship between participants' BMI (x-axis) and their subjective estimation of body size (PSE), with the effects of psychological state statistically controlled; B) the relationship between participants' BMI (x-axis) and fitted values of estimated body size (PSE) computed from the mixed model at ± 1SD of the mean PSYCH value for each group.*

As presented in **Figure 1.14**, control participants show contraction bias in their size estimation performance when the yes-no task is used. However, this effect is not replicated when method of adjustment is used (MoA). For example, Cornelissen, McCarty, Cornelissen, and Tovée (2017) found that accuracy of size estimation was influenced by the paradigm used. In the yes-no task, controls showed a pattern of responses consistent with contraction bias (Poulton, 1989). In the method of adjustment contraction bias was absent, Cornelissen et al. (2017) explain that this effect is likely due to an “anchoring effect” in the MoA task; the anchors are the visual stimuli that show the participant the smallest and largest body size in the stimulus range when the slider is adjusted. This link between movement of the slider and the direct visible change in the stimuli seems to be responsible for the lack of contraction bias (Cornelissen et al., 2017). Interestingly, anorexic (ANSD) participants’ responses do not follow the contraction bias pattern regardless of task used and instead show a unique pattern of performance suggesting that perhaps a different mechanism drives their performance.

Furthermore, accuracy of size estimation is also influenced by body shape concerns. **Figure 1.14** shows that for a body of a given BMI, the degree of over- or under-estimation is also modulated by the psychological state of the observer, in both control and ANSD participants.

Point of view / body ownership

Recent research has identified other, hitherto unrecognized, influences on judgments of body image: specifically, the effects of point of view and body ownership (Preston & Ehrsson, 2014). Typically, when participants make judgements about body size, the stimuli are presented on a monitor. This means that participants are making a judgement about their own body in relation, usually, to a standard model or a photograph of themselves, presented on a screen, and this constitutes a third person perspective: "that is a picture of me/someone else, over there". Normally however, to see our bodies in real time we need to look in a mirror or look down, for example, and this constitutes a first-person perspective: "what I am seeing is me, here". To manipulate point of view experimentally, Preston and Ehrsson (2014) used a method known to induce the illusory ownership of a body. Participants wore a virtual reality head-mounted display, Cybermind Visette 45, through which they could see a mannequin's body from first person perspective, as another headset was positioned on the mannequins' head. The size of the mannequin body was presented as either wider or narrower than the participant's actual body. The illusion of ownership of the mannequin's body by the participant was achieved by combining this visual presentation with synchronous touch being applied to the abdomen of the participant and the mannequin, which the participant could also see. Preston and Ehrsson (2007) have demonstrated that this combination of proprioceptive experience and visual presentation induces the illusion of the participant feeling that they now reside in the mannequin's body, they have achieved ownership of it, i.e. perceived it as their own body (Ehrsson, 2007).

Preston and Ehrsson (2014) demonstrated that by “inhabiting” a slimmer body in this way resulted in participants judging their *actual body* as slimmer, and as a result they gave higher ratings of body satisfaction than they did before experiencing the illusion. This further demonstrates the links between the body and emotional experiences, i.e. how we perceive and how we feel about our bodies. Identification of emotional changes driven by altered body perception warrants further investigation.

This research suggests that adequate measurement of body image may require not only that experimental stimuli are as ecologically valid as possible – hence the potential need to create individual avatars of participants - but that the estimations of body size need to be made from both third (POV-3) and first (POV-1) person perspectives, in order that its role can properly be evaluated. We return to this concept in more detail in the Introduction to Chapter 5.

1.5 The Body schema

The focus on visually perceived body size distortion, may be overly simplistic, as other distortions have been found across all forms of subjective bodily experiences in eating disordered patients; from somato-tactile size distortions in the horizontal plane (Keizer, Smeets, Dijkermann et al., 2011; Keizer et al., 2012; Spitoni et al., 2015) and disturbances of proprioception and kinesthetic processing (Eshkervari, Rieger, Longo, Haggard, & Treasure, 2012; Guardia, Carey, Cottencin, Thomas, & Luyat, 2013), through to altered interoceptive (Pollatos et al., 2008) and extraceptive sensitivity and awareness (Zucker et al., 2013), decreased multisensory integration (Case, Wilson, & Ramachandran, 2012; Gaudio, Brooks, & Riva, 2014; Keizer, Smeets, Postma, van Elburg, & Dijkerman, 2014) and deficits in sensorimotor/proprioceptive memory (Chieffi et al., 2015). Such findings challenge the notion that individuals with eating disorders over-estimate their body weight due to visual distortions alone, and suggest that other forms of body representation, such as body schema, should be similarly affected.

The concept of a separate '*body schema*' has been proposed to account for the apparent dissociation between perceptual (visual) body representations, and the configural metrics employed during movement (Dijkerman & de Haan, 2007; Gallagher, 2005; Paillard et al., 1997, 1983; de Vignemont, 2010). The body schema was conceived by Head and Holmes (1911) as the postural schema. To quote Head and Holmes (1911):

"*By means of perpetual alterations in position we are always building up a postural model of ourselves which constantly changes. Every new posture or movement is recorded on this plastic schema, and the activity of the cortex brings every fresh group of sensations evoked by altered posture into relation within it. Immediate postural recognition follows as soon as the relation is complete*" (p. 187)

Currently, the body schema is conceptualised as a central representation of the body's spatial properties, including the length of the limb segments, their hierarchical arrangement, the configuration of the segments in space, and the shape of the body surface (Haggard & Wolpert, 2005). As such, the body schema is critical to our ability to guide movement of the body as it tells us the position and configuration of the body as a volumetric object in space. It is a continuously updated unconscious, action-related sensorimotor representation of the body, that guides actions on the basis of tactile, kinesthetic, visual and labyrithine inputs (Gaudio, Brooks, & Riva, 2014). It is elicited by action, whether this action is actual, anticipated or imagined (De Vignemont, 2010; Schwoebel & Coslett, 2005). However, while on-line afferent signals provide information relating specifically to body posture and limb configuration, there is no online sensory input that relates directly to the current lengths and widths of specific body-parts. This suggests the existence of a stored representation of the body's metric properties from which the current body state must be inferred (Longo, Azañón, & Haggard, 2010; Longo, 2016).

One way to visualise the components of such a complex representation is by analogy with the kinds of 3D models used when developing animated movies or computer games. Such models require three major components: i) a skeleton, or "rig", which comprises a jointed set of bones where the animator specifies bone lengths, which would be an offline representation, ii) a polygonal "mesh" or 3D surface which captures the air/skin boundary and represents the shape of the flesh on the bones, which would also be offline, and iii) would be a dynamic online "pivot" representation of the joint angles and rotational position of limbs in relation to each other (see **Figure 1.15** below).

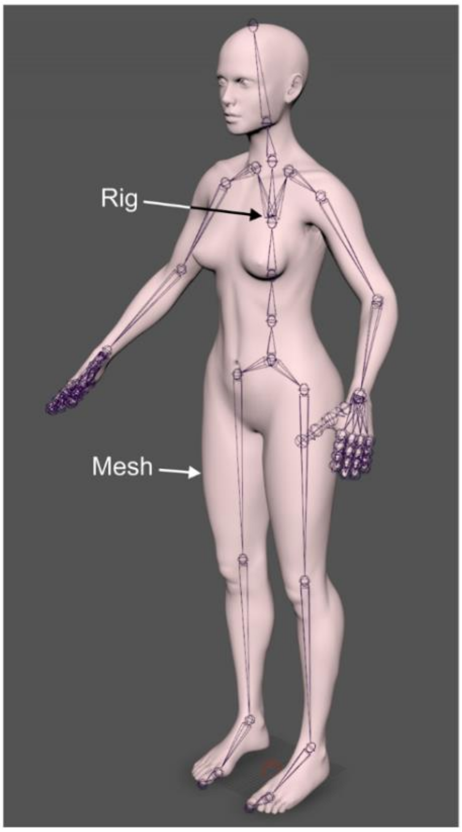

Figure 1.15. *Illustrates the distinction between the body 'rig' and the body' 'mesh' as defined in animatable CGI models.*

1.5.1 Disturbed body schema and body image in anorexia

In light of research demonstrating the disturbed experience of body size in eating disorders, researchers have asked whether the observed disturbances in body representation in anorexia nervosa could also extend to the body schema. For example, Keizer et al. (2013) measure the perceived passability of a gap between two wooden partitions, which looked like a doorway (cf. Warren and Whang, 1987). They identified the largest aperture, *A*, at which point participants just started to rotate their shoulders in order to walk through the gap. They also measured participants' shoulder width, *S*, and computed the critical ratio, *A/S*. Keizer et al. (2013) found this critical ratio to be larger for eating disordered participants, consistent with their false beliefs that their body was larger than reality.

Guardia et al. (2012) found a similar inflationary effect when eating disordered participants were asked to make perceptual judgements about the passability of a door-like aperture when viewed from a first person (egocentric reference frame) perspective, but not when they made the same judgements from the point of view of the investigator nearby (i.e. third person point of view, allocentric frame of reference). Guardia et al. (2012) suggested that over-estimation of the size of passable gap in women with anorexia nervosa may have been caused by over-estimation within their own personal body schema.

Intriguingly, Keizer et al. (2013)'s participants were also asked to estimate their own shoulder width, S_{est}, as a component of their body image. Not only was this estimate elevated in the anorexic participants compared to controls, but also when S_{est} was used in the critical *A/S* ratio calculation instead of *S*, they could no longer find a difference between the anorexic and control participants. This finding suggests an alternative explanation, it may be the *stored* body size information that is disturbed in anorexia, and this distorted metric information is used in turn by action-related body schema representations, leading to their inflated aperture estimates.

Interestingly, this idea has been previously put forward by Riva and Gaudio (2012) as part of the "Allocentric Lock Hypothesis". It posits that when integration of different sensory inputs within the allocentric and egocentric frames is disturbed, the egocentric sensory inputs are no longer able to update the perceptual allocentric representation, locking a person to it (Riva, 2012). In other words, according to this hypothesis, individuals with AN have negative allocentric representation, which is no longer updated by contrasting egocentric perceptual information about their own body, and as such must therefore rely upon a stored and distorted allocentric representation. A schematic representation of Allocentric Lock is presented in **Figure 1.16**.

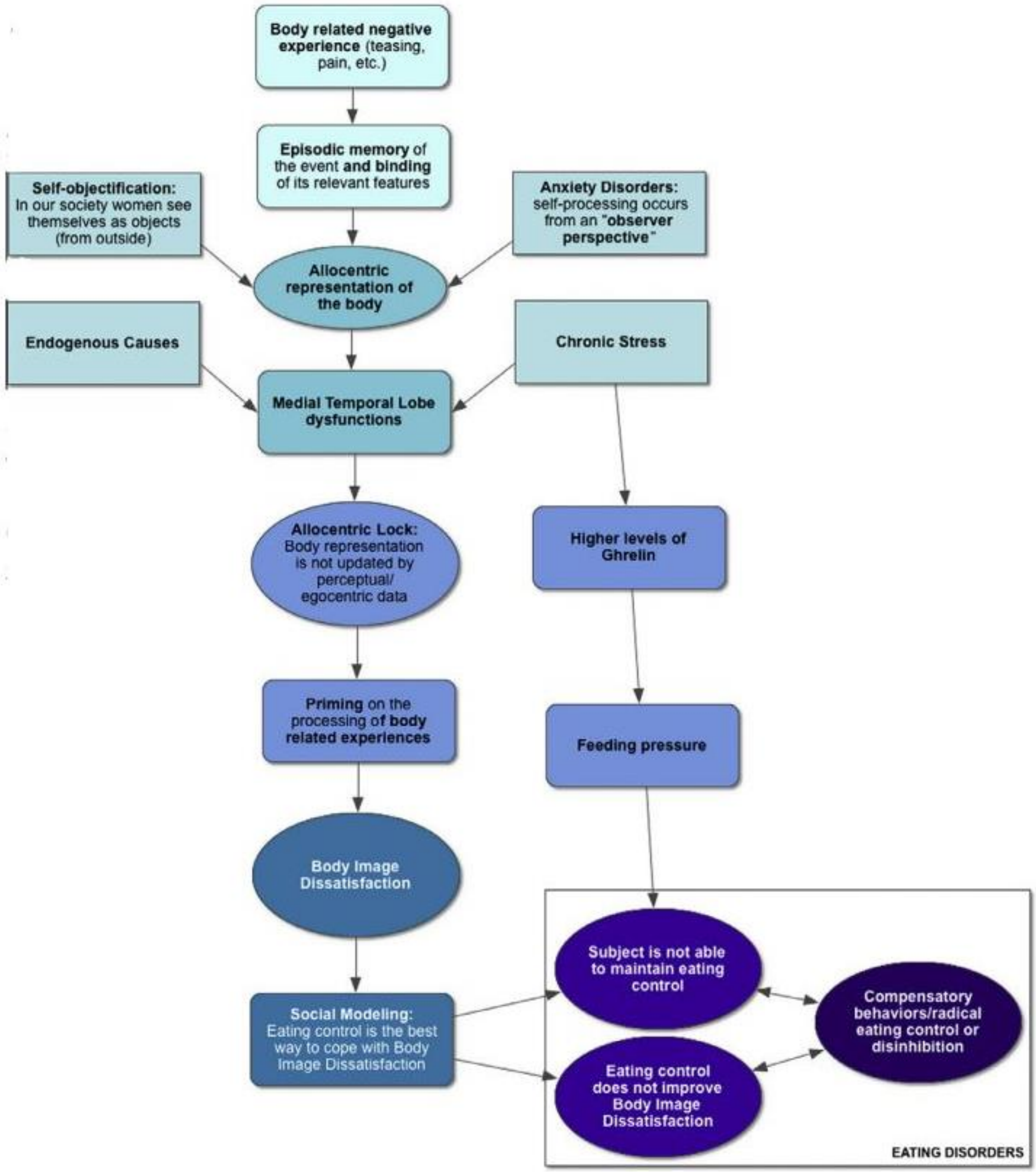

Figure 1.16. *A schematic presentation of the allocentric lock hypothesis (Riva, 2012).*

While support for the idea of a specifically “allocentric lock” has been equivocal, there is ample evidence to suggest that individuals with EDs are not able to optimally integrate incoming visual and proprioceptive/tactile/kinaesthetic information to update a current ‘online’ body percept (e.g. Keizer, Smeets, Dijkerman et al., 2011; Zucker et al.,

2013) and may therefore be relying upon a stored and distorted body representation. Support for this idea comes from functional imaging studies of AN participants that have demonstrated increased connectivity in cortical somatosensory areas implicated in long-term spatial memory and the spatial representation of body size, and a corresponding decrease in connectivity in areas sub-serving visual memory functions and visual perception of the body (Favaro et al., 2012).

Meta-analyses have consistently found evidence that supports the idea of separable domains of perceptual versus attitudinal body image, as described in prior sections. We argue that a complete picture of body image (i.e. one that maximises variance explained), requires information about both participants' perceptual judgements as well as attitudinal information about how they feel about their body: it is a multi-dimensional construct. Given the level of interdependence between perceptual and attitudinal aspects of body image when estimating body size (as illustrated in **Figure 1.14)**, and the fact that disturbances in body representation extend also to people with eating disorders, a wider question naturally arises: in what way might these two factors (i.e. perceptual and attitudinal body image) also interact with the body schema? This is a question we address in the first study of this thesis, reported in Chapter 3.

1.6 Treatment of eating disorders

Distorted evaluation of personal body size is also a key element of psychological models of anorexia nervosa (Cash & Deagle, 1997; Fairburn, Cooper, & Shafran, 2003). Body image distortion has been implicated in both the development and maintenance of anorexia nervosa, although debate continues as to whether it is a cause or a consequence of the disorder (Heilbrun & Friedberg, 1990). Furthermore, persistent body image distortion has been shown to predict the severity of the disorder, likelihood of relapse, and treatment failure (Gardner, 2011; Fairburn & Harrison, 2003; Slade & Russell, 1973). We now briefly review treatment options since this particular problem is the focus of Chapter 7.

The primary aim of eating disorder treatment is medical stabilisation, restoration of the individual's weight and treatment of comorbid medical conditions that threaten the individual's life. Once medically stabilised, treatment focuses on further restoration of weight to a healthy body mass index (BMI), nutritional rehabilitation and psychological treatment to address underlying psychopathology. Adjunct approaches can also be used, such as improving body functionality, i.e. focusing on what one's body is capable of rather than on what it looks like (Alleva, Martijn, Jansen, & Nederkoorn, 2013) and education programmes (O'Dea & Abraham, 2000; Zabinski, Wilfley, Calfas, Winzelberg, & Taylor, 2004; Winzelberg et al., 2000). Currently, a number of psychological therapies may be used in the care of AN individuals, these include psychodynamic, cognitive-behavioural (CBT), cognitive analytical therapy, interpersonal therapy, or a combination of these (Hay, Claudino, Touyz, & Elbaky, 2015).

From a psychological perspective, the current gold standard treatment is Cognitive-Behavioural Therapy (CBT); it combines behavioural exercises with rational disputation of a person's beliefs to modify dysfunctional thoughts, feelings and behaviours (Fairburn, 2012; Garner et al., 1997). Such treatment of body image pathology addresses a number of maintaining mechanisms such as selective attention, negative cognitions and affect, body checking and avoidance and detachment of appraisals of one's weight and shape from overall self-evaluation. CBT has been shown to lead to significant improvements in attitudes and behaviours related to eating disorders, as well as reducing associated psychopathology, such as depression (Fairburn, 2012). However, as we shall see, despite initial improvement, many patients do not improve after treatment ends, e.g. only half of women treated with CBT experienced long-term symptom reduction (Fairburn, Cooper, Shafran, & Wilson 2008) and others relapse; demonstrating that CBT is arguably only successful in the short-term.

Relapse is a significant problem in the treatment of anorexia, with rates reported to be as high at 22% - 51% (Berkman, Lohr, & Bulik, 2007; Castrol Gilla, Puig, Roriguez, & Toro, 2004; Channon & DeSilva, 1985; Herzog et al., 1999; Keel, Dorer, Franko, Jackson, & Herzog, 2005; Strober, Freeman, & Morrell, 1998). The bulimia literature reports higher rates of partial and full recovery (Herzog et al., 1999). Therefore, anorexia remains a frequently chronic and debilitating disorder; even after initial recovery and numerous treatments. The literature often identifies body image dysfunction as a key predictor of relapse (Keel et al., 2005). For example, Bardone-Cone et al. (2010) investigated four groups of women: fully recovered, partially recovered, active eating disorder and controls; the groups were categorised based on physical, behavioural and psychological indices. It was found that the recovered participants were indistinguishable from controls on all eating disorder related measures. While the partially recovered group, which was recovered physically and behaviourally but not psychologically, was similar to the eating disordered group in terms of disordered cognitions and body image-related measures such as body shame and thin-ideal internalisation. These results mirror that of Bachner-Melman, Zohar, and Ebstein (2006) who found that only women who were both cognitively and behaviourally recovered were comparable to controls in terms of body dissatisfaction and thin-ideal internalisation; however, women who were only behaviourally recovered, i.e. no longer fasted, binged or purged, were comparable to the anorexic group in terms of dissatisfaction, drive for thinness, disordered eating attitudes, amongst other symptomatology.

Importantly, is has been found that behavioural interventions, which do not address over-evaluation of eating, shape and size, were associated with an increased risk of relapse, compared to full treatment (Fairburn, Cooper, & Shafran, 2003). Additionally, the severity of body image disturbance can predict long-term outcomes, such as weight at 1 year follow up after discharge (Channon & DeSilva, 1985). In particular, patients who needed to be re-hospitalised following successful initial weight restoration, were found to not only present with symptomatology as previously described by Bachner-Melman et al. (2006) and Fairburn et al. (2003), but they were also found to over-estimate their hip size (Castro, Gila, Puig, Rodriguez, & Toro, 2004).

Even though Casper, Halmi, Goldberg, Eckert, and Davis (1979) have demonstrated that in AN patients, the degree of over-estimation was associated with less weight gain during treatment and greater denial of illness, studies of patient recovery often do not acknowledge the multi-faceted nature of body image, i.e. studies that include measures of patients' performance on size estimation tasks are sparse. An investigation by Sala et al. (2012) included such a measure, with a group of 34 AN patients who were gaining weight in treatment. It was found that participants' body dissatisfaction reduced, as did their body distortion. While a crude silhouette method was employed to measure body distortion, see **Figure 1.17**; the results still provide important information about the potential state of body image distortion in anorexia.

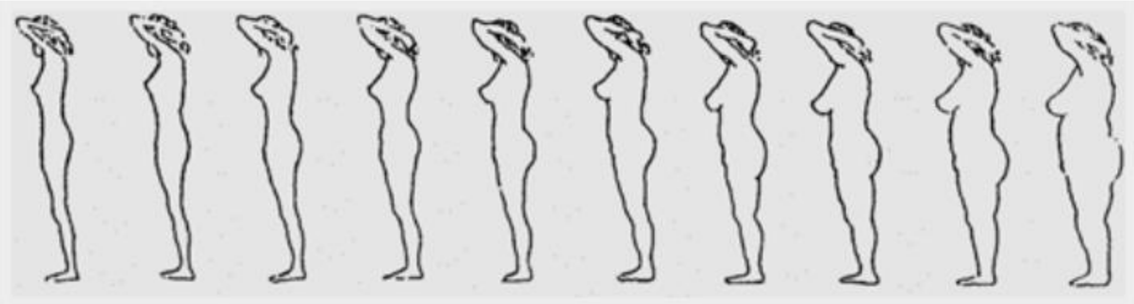

Figure 1.17. *Silhouette method utilised by Sala et al. (2012).*

Talking therapies can improve the cognitive-affective and behavioural component of body image. However, such therapies do not always address the issues related to perceptual body image; while feelings, beliefs and emotions can be talked about and challenged, addressing how the person visualises themselves to look like is not straight forward (Bruch, 1962; Cash & Deagle, 1997; Gardner & Brown, 2013).

A number of approaches have attempted to target distorted body image. For example, one of the techniques used in cognitive behavioural therapy (CBT) is mirror exposure in order to desensitise, i.e. encourage anorexia patients to pay less attention to changes in body shape and weight (Key et al., 2002). Improvements were found in body satisfaction and anxiety, along avoidance behaviours. Similar studies have found that mirror exposure improved body checking and avoidance, as well as weight and shape concerns, body dissatisfaction, dieting, depression and self-esteem (Delinski & Wilson, 2005; Vocks, Legenbauer, Wächter, Wucherer, & Kosfelder, 2007). These approaches, however, do not directly address size estimation; neither have they measured if any changes in perceptual body image took place.

Two recent studies have attempted to modify the perception of body size, both were inspired by research carried out by Penton-Voak et al. (2013) to modify biases in emotion recognition. In this study, participants at risk of criminal offending and delinquency were presented over a number of trials with images of faces. On each trial they had to decide whether the face was happy or angry. The faces were drawn at random from a sequence that morphed continuously from clearly happy to clearly angry. Images in the middle of the sequence (intermediate in their expression) could be judged either way. For each participant, a subjective threshold for happy / angry emotional categorisation along the continuum was established. Adolescents at high risk of offending tended to categorise even intermediate faces as angry, compared to controls. However, by giving appropriately structured feedback, Penton-Voak et al. (2013) were able to shift individuals' categorical boundaries towards the 'happy' end of the spectrum. Intriguingly, this perceptual shift also resulted in decreased self-reported anger and aggression, as well as reduced aggressive behaviour as assessed by independent raters. The same paradigm was used in an earlier study by Penton-Voak et al. (2012) to recalibrate the perception of happiness over sadness in ambiguous facial expressions in people reporting high levels of depressive symptoms, in the attempt to improve their mood.

Gledhill et al. (2016) adapted this technique to move individual participants' categorical boundaries for thin-fat judgments of bodies towards fatter bodies. At baseline on each of four training days, participants judged the body size of a series of female bodies in order to establish the categorical boundary for thin / fat for that day. The categorization task was then repeated. But this time, for those in the intervention group, inflationary feedback was used to move participants' categorical boundaries towards bodies fatter than at baseline. This way participants were retrained to judge bodies near their thin/fat categorical boundary which they have previously judged as fat, to now report them as thin. In the control condition, feedback was used, but it merely reinforced the baseline response. Gledhill et al. (2016) successfully shifted the thin-fat categorical boundary in individuals with high body concerns who received inflationary feedback. A significant reduction in scores on measures of restraint, body size and shape concern was also found. These changes were retained at 2 weeks follow up. While further investigation is needed, the results demonstrated the potential of this technique to improve body image.

In a very similar study, Szostak (2018) also used cognitive bias modification to manipulate the interpretation of body size, and to encourage the interpretation of thinness over heaviness in normal-sized bodies; while investigating the effect of such manipulation on personal body satisfaction and body ideals. In the intervention condition participants received inflationary feedback, to move their categorical boundary towards thin bodies, i.e. to interpret bodies previously categorised as heavy as thin. Szostak (2018) successfully shifted the categorical boundary towards thinness, retained at 2 week follow up. Furthermore, in the intervention group the shift in threshold was accompanied by more favourable attractiveness and ideal ratings of heavier bodies at 2 week follow up in contrast to the baseline, along with lower levels of body dissatisfaction.

These results are encouraging, suggesting that training designed to address body image disturbance has the potential to complement existing therapies. We return to this topic, when we attempt to replicate Gledhill et al. (2016) in Chapter 7.

1.7 Rationale and research questions

The literature presented in the Introduction provided an overview of the the concept of body image, with particular focus on the two components: attitudinal and perceptual (as well as tools of their measurement). We also presented evidence that disturbances in body representation likely also extend to body schema in people with eating disorders. We believe that this review has demonstrated that historically attitudinal body image has received more scientific attention than the perceptual component. This difference may partially be explained by difficulty in measurement of perceptual body image. Lastly, we briefly described literature on existing eating disorder treatment approaches, again demonstrating that such therapies do not always address the issues related to perceptual body image. Treating percpetual body image is arguably more challenging, especially as the component has been under-studied. As such, the review presented in the Introduction raised a numer of questions regarding the concept of body image.

Firstly, considering the reported disturbances at different levels of body representation, and given the potential functional ties between them, we asked how the three levels of representation (attitudinal body image, perceptual body image, body schema) may normally interact with each other.

Secondly, considering the importance of own size estimation as a key feature of both anorexia and bulimia nervosa, we asked which body areas (edge vs internal/central cues) are used to judge body size across accurate and inaccurate body size estimators; we aimed to localise the visual features used in body judgements.

Next, recent research raised the question of body ownership and whether estimates of body size should be made from first- or third-person perspective. To that end, we wanted to investigate whether participants can identify their bespoke avatars created on the basis of their body shape and size alone; and whether body size estimates are more or less accurate and precise when made in immersive virtual reality, as compared to conventional 2D display method.

Lastly, existing treatment interventions addressing the perceptual component of body image are extremely limited. As this component predicts treatment success and relapse rates, it is important to develop effective treatment for perceptual body image distortion. To that end, in our last study we attempted to replicate and extend an existing intervention paradigm known to recalibrate perception of thin/fat bodes (and to reduce psychological concerns) using immersive virtual reality.

Chapter 2: General methods

To avoid repetition in the experimental chapters, this chapter introduces a number of tools and instruments that have been employed in most of the investigations in this thesis. In particular, across all studies presented in the experimental chapters we have used the same psychometric measures as described in section 2.2 below. The psychophysical methods described in section 2.3.2 were used in all but study 7.

2.1 BMI measurements

Participant' Body Mass Index was calculated from their weight and height measured with a set of calibrated scales and a stadiometer following the formula: BMI = kg/m^2. For the height measurement participants were instructed to remove shoes, stand straight, and look ahead with their chin raised. For the weight measurement, a calibrated scale was used, the scales were positioned on a solid, even surface, and participants stood in the centre of the scales until a clear measurement was apparent.

2.2 Psychometric measures

We used a variety of well-established self-report questionnaires to investigate individuals' attitudes towards their body shape/size, weight and eating, as well as their tendency towards depression, and their self-esteem. The internal consistency of each measure is reported in the method section of each study.

To investigate body shape and size concerns and eating habits we used The Eating Disorders Examination Questionnaire and the Body Shape Questionnaire.

The Eating Disorders Examination Questionnaire (EDE - Q, Fairburn and Beglin, 1994), is a self-report measure derived from the Eating Disorder Examination interview (EDE; Fairburn & Cooper, 1993). It is widely used to assess key attitudes, feelings and behaviours related to eating and body image over the past 28 days. The questionnaire measures four independent aspects of eating disorder behaviour:

Restraint (res), Shape Concern (SC), Weight Concern (WC) and Eating Concern (eat) yielding a separate score for each aspect, as well as a Global score, which is the average of the four subscales. Each aspect is assessed on a 7-point Likert scale, ranging from 0 indicating 'no days' to 6 indicating 'every day'. The five items of the Restraint sub-scale measure the restrictive nature of eating behaviour (e.g. avoidance, dietary rules). The five items of the Eating Concern sub-scale measure preoccupation with food and social eating (e.g. secretive eating, guilt). The eight items of the Shape Concern sub-scale measure dissatisfaction with one's own body shape (e.g. desire to look different, cognitive pre-occupation with shape). The five items of the Weight Concern sub-scale measure dissatisfaction with body weight (e.g. desire to lose weight, cognitive pre-occupation with weight). The subscales can be used to calculate the overall eating disordered index, where values above 4 are treated in screening situations as an indication of an eating disorder. The questionnaire also included 6 items collecting frequency data on some vital behavioural features of eating disorders, such as purging and binging behaviours.

The EDE-Q has been extensively researched with a variety of samples in the UK, USA, Australia and Europe (e.g. the Netherlands, in English) and has been normed for eating disordered, community samples and over-weight samples across variety of age groups, e.g. high school, college, and "older" (Aardoom, Dingemans, Slof Op't Landt, & Van Furth, 2012; Hay, Rodgers, & Owen, 2006; Luce, Crowther & Pole, 2008; Mond et al., 2008). The scale accurately discriminates between participants with and without an eating disorder diagnosis (Aardoom et al., 2012; Mond et al., 2008) and its internal consistency has been reported at α = .90 (Peterson et al., 2007). The four sub-scales of the EDE-Q have been investigated, the restraint subscale's Cronbach's α has been reported to vary between .70 and .85, eating concern between .73 and 78, shape concern between .92 and .93, and weight concern between .72 and .89 (Peterson et al. 2007; Luce & Crowther, 1999). Luce and Crowther (1999) also reported excellent test-retest reliability. Lastly, Luce et al. (2008) further reported high convergent validity between the EDE-Q and EDE; the questionnaire version was chosen as an efficient and cost-effective alternative to the interview, which would require extensive training.

The 16-item Body Shape Questionnaire (BSQ), the Body Shape Questionnaire was originally developed by Cooper, Taylor, Cooper, and Fairburn (1986); the shortened 16-item version used here was developed by Evans and Dolan (1993). The BSQ is a self-report measure assessing size and shape concerns over the past four weeks. The BSQ includes questions that tap into important body image symptoms, e.g. preoccupation and attitudes towards body size and shape, avoidance of activities or exposure of one's body due to self-consciousness (Probst, Pieters, & Vanderlinden, 2008). The questionnaire items were created based on semi-structured interviews with various groups of women, including eating disordered participants. The BSQ is scored on a 6-point Likert scale, where 1 indicates 'never' and 6 indicates 'always', with a range of 16-96. Scores below 38 are indicative of no shape concerns, scores of 38-51 show mild concerns, scores of 52-66 show moderate body shape concerns, and scores of 66 and above are considered to indicate 'marked concern with shape' – a sign of body dissatisfaction (Evans & Dolan, 1993).

The BSQ has been reported to have internal consistency of .82 (Probst et al., 2008). This shortened version has also been reported to correlate well with the original 34-item scale by Cooper et al. (1986), which itself was found to have good test-retest reliability, concurrent validity with other measures of body image, and criterion validity for clinical status. This suggests that the alternate, shortened version is an appropriate tool in itself. Lastly, Probst et al. (2008) investigated a variety of different body experience questionnaires and concluded that the BSQ (amongst others) was appropriate in differentiating those with and without eating disordered pathology; with internal consistency ranging from α = .82 to α = .94, the scale can also differentiate between those high in body image concerns and those who are not.

To assess our participants' levels of depression and self-esteem the Beck Depression Inventory (BDI) and Rosenberg Self-Esteem Scale (RSE) were used.

The Beck Depression Inventory (BDI) was developed by Beck, Steer, Ball, and Rainieri (1996) and is the most recent revised version of the original instrument by Beck, Ward, Mendelson, Mock, and Erbaugh (1961). The BDI is a 21-item self-report measure assessing the severity of depression over the past two weeks. It covers symptoms of depression such as hopelessness and irritability, cognition, as well as physical symptoms. Each item is answered on a 4-point (0-3) scale, where 0 indicates no change in behaviour (e.g. 'I have not lost interest in other people or activities'), and 3 indicates increased severity (e.g. 'It's hard to get interested in anything'). Scores range from 0 to 63, whereby a score over 29 is considered to indicate severe depression.

Generally, the psychometric properties of the BDI are good. Coefficient alpha estimates of reliability in an adult outpatient sample has been reported at $\alpha = .93$ (Beck et al., 1996), similarly it has been reported at $\alpha = .91$ with a nonclinical sample (Dozois, Dobson, & Ahnberg, 1998). The test-retest reliability reported by Beck et al. (1996) was supported by Sprinkle et al. (2002) in a clinical sample, the total score of test-retest was $r = .96$. The BDI was found to correlate strongly with other self-report measures that identify depression, such as the Primary Care Evaluation of Mental Disorders and Patient Health Questionnaire (Arnau, Meagher, Norris, & Bramson, 2001). The BDI was also found to correlate highly with the original BDI in an adult outpatient sample (Beck et al., 1996) and nonclinical university student sample (Dozois et al., 1998). However, due to more clearly delineated factor structure of the BDI, it has been recommended as a stronger instrument than the original (Dozois et al., 1998).

The Rosenberg Self-Esteem Scale (RSE) developed by Rosenberg (1965) is a 10-item self-report measure assessing participants' self-esteem by reflection on current feelings. The items are answered on a 4-point scale (0-3), with 0 indicating 'strongly disagree' and 3 indicating 'strongly agree'. Five of the items have positively worded statements, and five are worded negatively. Higher scores indicate higher self-esteem.

The RSE is likely the most widely used measure of global self-esteem, it has been translated into multiple languages and used in a variety of research contexts. One international study of 53 nations (n = 16,998) translated it into 28 languages and revealed a mean Cronbach's alpha of .81 (median = .82) (Schmitt & Allik, 2005). The study also revealed a Cronbach's alpha of .90 for the United Kingdom (n = 480) (Schmitt & Allik, 2005). Compared to another self-esteem measure, the Coopersmith Self-Esteem Inventory, the RSE was deemed the most appropriate measure of self-esteem for dieting disordered patients and was found to be a significant predictor of dieting disordered psychopathology, while the Coopersmith scale was not (Griffiths et al., 1999). Griffiths et al. (1999) concluded the RSE to have sound construct and convergent validity.

2.3 Psychophysical Methods

2.3.1 Stimulus creation and calibration

The stimuli and programmes for the psychophysical tasks were the same as those reported in Cornelissen (2016). The following section provides a brief description adapted from this thesis, with permission.

The female body stimuli were created in the Daz Studio v4.8 modelling environment, which allows manipulation of the body shape of a fully rigged digital model. The base model used was Victoria 6. In Daz, from the neck down there are 320 body shape controls, 16 of which change whole-body attributes such as adiposity. There are an additional 209 controls for the head features. The base model was modified to illustrate the average body shape (height, leg length, and the circumferences of bust, under-bust, waist and hip) of a 25 year old UK Caucasian female, based on the data from the Health Survey for England (HSE) 2008 dataset. This model provided a baseline whose adiposity could then be systematically modified. Cornelissen (2016) presents details of qualitative model validation, which will not be repeated here; below we present a brief explanation of how Cornelissen (2016) calibrated the models.

The models had to be calibrated for BMI in order to accurately capture realistic body changes across a wide range of BMIs. To derive a calibration equation for BMI, information about height, waist and hip circumferences, and age was extracted from the Health Survey for England (HSE) 2008 dataset. **Figure 2.1** below presents the relationships between BMI and hip circumference, waist circumference, height and age for 4976 Caucasian females in the UK.

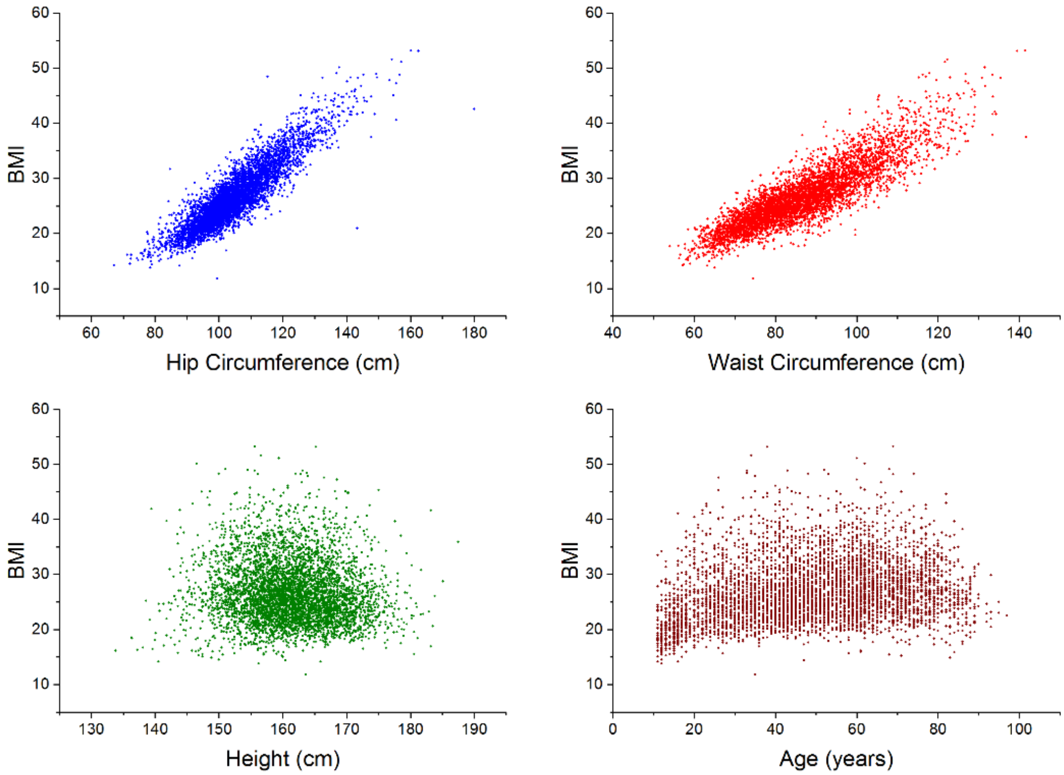

Figure 2.1 *Scatter plots of BMI as function of: hip circumference, waist circumference, height and age of the 4976 females in the HSE 2008 dataset Reproduced from Cornelissen (2016) with permission.*

To derive the calibration curve, Cornelissen (2016) used PROC REG in SAS v9.3 to compute a multiple regression of BMI on waist and hip circumferences, height and age from the HSE 2008 dataset. Second order polynomial fits were assessed for height and age. The final model was optimised by maximising r-square and minimising Mallow's CP. The best fit model explained 90.24% of the variance in BMI and was:

$$y_i = \beta_0 + \beta_1.x_1 + \beta_2.x_2 + \beta_3.x_3 + \beta_4.x_4 + \beta_5.x_4^2 + \epsilon_i$$

Where y_i = BMI, x_1 = hip circumference, x_2 = waist circumference, x_3 = height, x_4 = age, β_0 = 9.676, β_1 = 0.308, β_2 = 0.150, β_3 = -0.179, β_4 = 0.0554, β_5 = - 0.000762 and ϵ_i = residual error. Each term in the model was statistically significant at p <.0001.

In the Daz Studio environment the base model was set to: the height 1.65m, waist circumference 69cm, hip circumference 91.3cm, and underbust circumference 73cm, all of which are the averages for Caucasian females aged 18 to 45 in the UK from Health Survey for England 2008. The model's waist and hip circumferences were measured using the Measure Metrics tool in the Daz studio environment; using these values the model's BMI could therefore be estimated from the calibration equation.

The model's shape/size was changed using three controls: emaciated, thin, and heavy. Each controller varies the body shape component it is responsible for between a minimum of 0 and maximum of 1. For example, when the heavy controller is set to 1 it presents the highest possible fatness (adiposity) of the model. The heavy controller affects the bodily areas most affected by obesity, while the thin controller affects more general changes across the body. The emaciation controller when set to 1 presents the most severe emaciation permitted by the model, i.e. skeletal structure becomes clearly visible and the model's muscle mass is severely depleted.

To animate a sequence of frames ranging from the thinnest to the fattest body four key frames were selected. Key frame 1 corresponds to the body at its thinnest with most severe emaciation. Key frame 2 represents a thin but not emaciated body. In key frame 3 the body is 'neutral', and key frame 4 presents the body at its fattest. The morph control settings corresponding to these key frames were:

Key frame 1: emaciated = 1, thin = 1, heavy = 0

Key frame 2: emaciated = 0, thin = 1, heavy = 0

Key frame 3: emaciated = 0, thin = 0, heavy = 0

Key frame 4: emaciated = 0, thin = 0, heavy = 1

The next step was to decide how many frames Daz should interpolate between these key frames. Cornelissen (2016) reports that their pilot testing showed that allowing Daz to animate the key frame sequence over 310 frames would allow the creation of 120 stimulus images, covering the BMI range between 12 to 42.5 in 0.25 BMI unit increments (at accuracy of ~ +/- 0.07BMI units per frame). Additionally, the size of the BMI change between key frames 3 and 4 was approximately twice that for either key frames 1 and 2 or from 2 to 3, therefore approximately twice the number of animation frames were assigned to this part of the animation sequence to achieve the same accuracy in BMI increments. In **Figure 2.2** below, this is reflected in the larger gap between key frames 3 and 4, than between key frames 1 & 2 and 2 & 3.

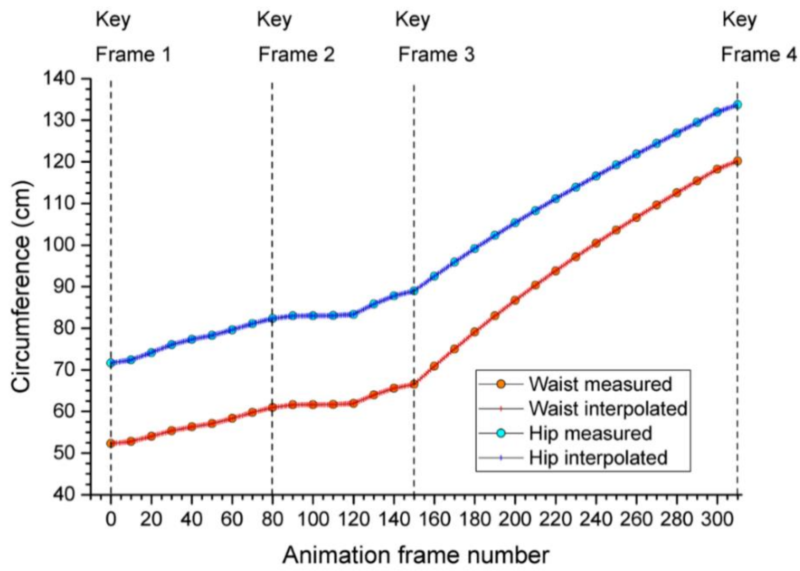

Figure 2.2 *A plot of CGI model waist and hip circumferences as a function of animation frame number, along with the location of the animation key frames. Reproduced from Cornelissen (2016) with permission.*

The Measure Metrics tool was used to extract the waist and hip circumferences every 10^{th} frame in the 310-frame sequence. For the animation frames in between the measured frames, linear increases were assumed for both waist and hip circumferences. PROC EXPAND in SAS v9.3 was used to linearly interpolate the 9 values between each measurement point. **Figure 2.2** shows a plot of the relationship between model waist and hip circumferences as a function of animation frame number. The values for waist and hip circumferences were applied to the calibration equation, as presented above, to identify the frames which most closely corresponded to the BMI range of 12.5 to 42.5, in increments of 0.25 BMI units. These images were then rendered for the stimulus set at 1024h x 576w pixels (24bit colour depth). This also meant that the underlying skeletal proportions, posture, skin, clothes, hair and lighting did not change through the stimulus sequence, only adiposity and muscle mass changed. All rendering was done using a physically based, unbiased rendering engine that results in physically correct image synthesis. We used Lux Render version 1.6 interfaced via the Reality Plugin v2.5 in DaZ 4.8. The stimuli were then used in the tasks described below.

2.3.2 Psychophysical tasks

The psychophysical tasks were written in Python 2.7 (32-bit) for Windows using the PyGame framework.

Yes-No task; in this task participants were presented with a randomised sequence of standardised CGI of a female body, the stimuli were developed as described above by Cornelissen (2016). The BMI of the images varies continuously from 12.5 to 42.25, and the participant is tasked with responding with a button press to each image, pressing the Z key if they believe the stimuli to be smaller than them (as in ‘no, this body is smaller than me’), and the M key if they believed it to be larger than them (as in, ‘yes, this body is larger than me’).

The task measures the point of subjective equality (PSE), which is defined from the psychometric function as the BMI at which the participants responds ‘larger than me’

50% of the time (see **Figure 2.3**, left side) – i.e. they are at chance level. Because the PSE represents a complete lack of discrimination, this value corresponds to the body size that participants believe themselves to have. The task also measures the difference limen (DL), which is the smallest change in stimuli that the participant can detect, i.e. their sensitivity to changes in body size. The DL has a lower and upper part, the lower part is the difference in BMI falling between the 25% 'larger' response points on the psychometric function and the PSE. The upper part is the difference in BMI falling between the 75% 'larger' response points and the PSE. The average of the two is an estimate of DL. The DL captures the steepness of the psychometric curve and corresponds to how sensitive a participant is to changes in body size (see **Figure 2.3**, right side).

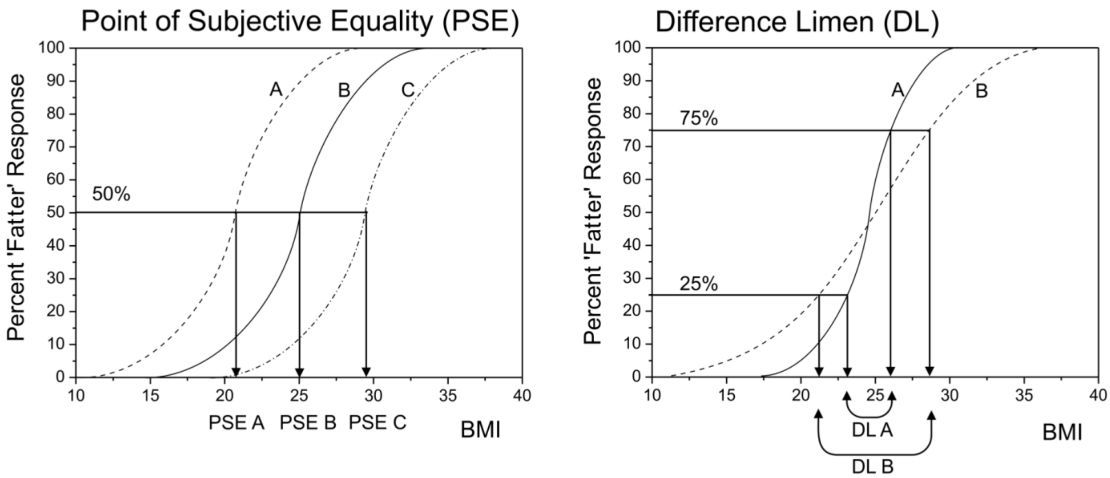

Figure 2.3 *A graphical illustration of how the psychometric function for body size estimation can be used to separate out sensory sensitivity (indexed by the difference limen, DL) from perceptual bias (indexed by the point of subjective equality, PSE). In the left figure, participants A, B and C might all have the same BMI of 25. Participant A under-estimates and participants C over-estimates their body size. On the right, participant A is more sensitive to body size change than participant B, and therefore has a steeper psychometric function, with smaller DL. Reproduced with permission from Cornelissen (2016).*

The stimuli were presented on a 19" flat panel LCD screen (1280w x 1024h pixel native resolution, 32-bit colour depth) for as long as it took participants to make a decision. At the standard viewing distance of ~60cm, the image frame containing the female body subtended ~26° vertically and ~8° degrees horizontally. Each participant first judged seven images covering the whole BMI range (from 12.5 to 44.5 in equal BMI steps) presented in two separate blocks. Each stimulus image appeared 10 times in each block, and the order of presentation was randomised. Based on the responses from each block, the participants' point of subjective equality or PSE (the BMI they believe themselves to be) was calculated automatically by fitting a cumulative normal distribution. These two values were then averaged to give an initial estimate of the participant's PSE. On the basis of this initial estimate, the program presented a further set of 21 images (spread over a range of 5 BMI units centred on the participant's initial PSE, at a spacing of 0.25 units per image) for the participants to judge. This final set of judgements allowed us to plot the full psychometric function (i.e. the proportion of 'larger' responses on the y-axis as a function of stimulus BMI on the x-axis) and use probit analysis off-line to calculate a definitive estimate of PSE as well as the difference limen or DL.

There was no time limit to this task, and each image was presented on the screen for as long as it took the participant to make a decision. The task would typically last 15-20 minutes per participant.

Method of adjustment (MoA) task: Participants used the method of adjustment to estimate their body size with the same stimulus set as for the yes-no task. Participants carried out 20 trials using the same display setup as for the yes-no task. On each of these 20 trials, the stimulus appeared on screen, and beneath the stimulus was a slider control (see **Figure 2.3**). The participant was asked to click on the slider control to move it from side to side. When the slider moved leftwards the BMI of the avatar reduced smoothly to a minimum of 12.5; and increased to a maximum of 44.5 when the slider moved rightward. The participant had to decide what body size of the stimulus best matched the body size they believed themselves to have, and then press a radio button, marked 'Continue', on screen that allowed the stimulus PC to log their response and initiate the next trial. At the start of each trial, the BMI of the avatar was set randomly to either its minimum, with the slider appearing at the leftmost extreme of its range of movement, or the maximum BMI, with the slider appearing at the rightmost extreme of its range of movement; see **Figure 2.4**.

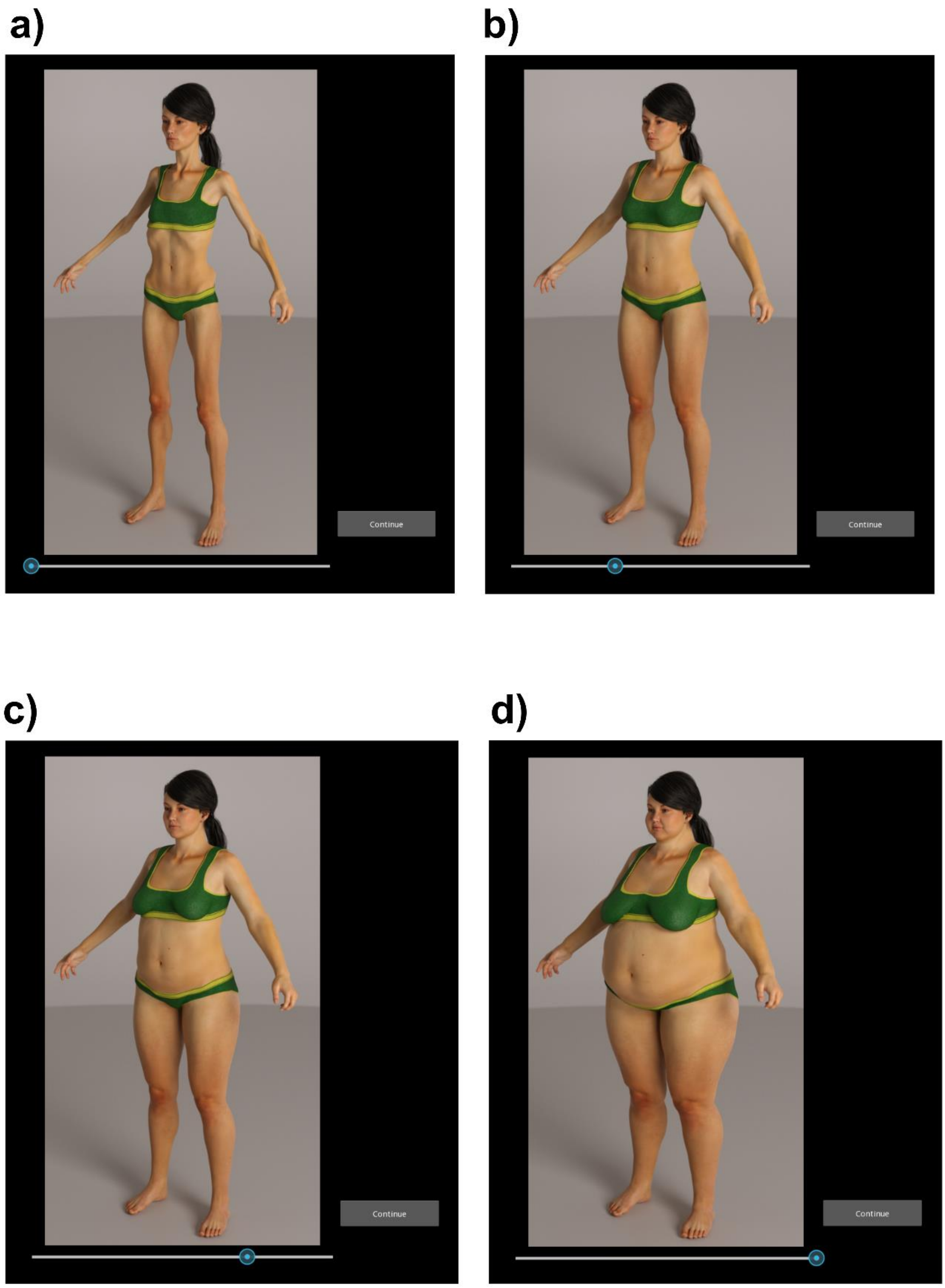

Figure 2.4 *Body shape changes for the standard model stimulus as the slider control is moved from left to right through screenshots a, b, c & d.*

Chapter 3: Study 1 - Body image and body schema

In this study, we investigated how attitudinal body image and perceptual body image interact with the body schema within a typical, healthy population. Adult women (n=100) were asked to carry out a motor imagery task, judging the smallest gap between a pair of sliding doors that they could walk through. We then determined whether these estimates were sufficient to predict the size of the smallest gap they could actually pass through, or whether perceptual and attitudinal body image information was required in order to make these predictions.

3.1 Introduction

Section 1.4.4 of the Introduction described the level of interdependence between perceptual and attitudinal aspects of body image when healthy controls and people with eating disorders estimate their body size (as illustrated in **Figure 1.14**). Section 1.5.1 then described how disturbances in body representation have been shown to extend to individuals with eating disorders. In light of research demonstrating the disturbed experience of body size in eating disorders, researchers have naturally asked whether the observed disturbances in body image representation in anorexia nervosa could also extend to the body schema.

Unfortunately, neither of the described studies, i.e. Keizer et al. (2013) and Guardia et al. (2012), analysed their data in a way that directly addresses this question either with respect to healthy controls or eating disordered individuals. Nevertheless, Guardia et al. (2012) did report positive correlations between attitudes to body shape and eating, and their equivalent to the critical *A/S* ratio, as well as between the critical *A/S* ratio and body size estimation, computed across their whole sample of 25 anorexic and 25 controls. This suggests that there may be important patterns of interdependence between these three domains (i.e. perceptual and attitudinal body image and the body schema). In fact, a more recent study by Engel and Keizer (2017), which included measures of bodily attitudes and visual and tactile perceptual judgements, as well as motor affordances, found that individuals with current EDs did have stronger negative body attitudes than healthy controls, or individuals who completed ED treatment. Nevertheless, none of these authors carried out any further analyses that pitted critical *A/S* ratio, body size estimation, affordance perception and body image attitude against each other. Therefore, it is currently unknown under what circumstances these factors may or may not have influences each other in these studies.

We argue that the eating disorders literature provides suggestive hints at how these three levels of representation may normally influence each other. Of particular interest is the observation of Keizer et al. (2013), as described in section 1.5.1 of the Introduction, who substituted S_{est} for S in their critical A/S ratio measurements, and could no longer find a difference in A/S_{est} between eating disordered and control participants. This strongly suggests that it might only be individuals with relatively high concerns about body shape/weight and eating who make use of their distorted perceptual body image during a motor imagery task. It seems that it may be the affective salience of the distorted *stored* body representation that mediates the degree to which it is incorporated into the current body state when making egocentric perceptual judgements. Accordingly, we decided to take advantage of individual differences in otherwise healthy women, who exhibit very wide variation across a spectrum of eating/body shape concerns (Luce, Crowther, & Pole, 2008; Mond et al., 2006), and use a correlational design with a sample size large enough to compute mediation/moderation analyses. This study aimed to reveal the normal patterns of interaction between the perceptual and attitudinal aspects of body image and the body schema in adult women.

Our strategy was to ask participants to make two kinds of egocentric judgement, both of which should be most sensitive to body size, shape, and adiposity/muscle mass, i.e. the judgements should be heavily biased by the horizontal dimensions of the body ‘mesh’ as compared to the largely vertical dimensions of the ‘rig’ (see **Figure 1.13** in

Introduction). For the first judgement, which indexes the body schema, participants carried out a task similar to that used by Guardia et al. (2012, 2010) and Keizer et al. (2013). Participants were asked to estimate the smallest gap between a pair of moving sliding doors that they could just pass through without rotating their shoulders. This method was also previously used by Warren and Whang (1987) to determine whether such perceptual judgments differed between static and dynamic movement conditions. They measured large and small participants' critical *A/S* ratios to identify the phase transition from frontal walking to body rotation and compared these results with motor imagery or "passability" judgements made under both static and moving viewing conditions. They concluded that i) the critical *A/S* ratios were comparable between natural walking, and when participants made both static and moving passability judgements; ii) at a bare minimum, passability can be accurately judged when participants were standing still and viewing the aperture to be judged with just one eye, i.e. they are merely imagining walking through the gap. The additional kinetic information available from real movement together with binocular visual cues, is not necessary. Therefore, we would suggest that such a motor imagery task, in which participants are standing still, is appropriate for assessing egocentric body schema integrity (Guardia et al., 2010; Guardia et al., 2012; Schwoebel & Coslett, 2005; de Vignemont, 2010). In order to provide a 'baseline' of gap estimation ability we also included a purely allocentric (non-body-related) control condition, in which participants were asked to make the same judgements for a yoga ball. Using a non-body-related object ensured that there were no possible interactions with attitudinal body image, or any confounds caused by bodily comparisons between participants' own bodies and a body-shaped exemplar.

For the second form of egocentric judgement, which indexes the visual perceptual (and possibly conceptual) aspect of body image, we asked participants to make both yes/no and method of adjustment decisions. To index the attitudinal aspect of body image, we used a number of psychometric tasks that assess concerns about body shape and weight, eating habits, tendency towards feelings of depression, and self-esteem.

The first prediction was that we should be able to replicate the multidimensional nature of body image representation as found by Cornelissen et al. (2015). Specifically, it was predicted that psychophysical estimates of body size, indexing the body image, should best be predicted (i.e. maximum variance explained) by linear combination of both, participants' BMI and their psychometric performance.

Our second prediction was confirmatory and required us to obtain 3D body shape scan data from each participant. We predicted that participants' BMIs, their gap size estimates, and the smallest aperture that they could actually pass through should all be highly correlated with each other, and correlated with latent variables from participant's 3D scan data that reflect horizontal/volumetric variability of mash (e.g. abdominal and limb girth and body volume) and not vertical variability of the rig (e.g. torso and limb segment length).

Our third and more important prediction, following the findings of Keizer et al. (2013), was that: i) aperture judgements in a motor imagery task should statistically predict, the smallest gap that participants can actually pass through (i.e. the DIRECT path in **Figure 3.1**); ii) this prediction should be mediated at least in part by participants' perceptual body image; the size and shape they believe themselves to have (i.e. the INDIRECT path in **Figure 3.1**); iii) the extent of this mediation should be moderated by participants' attitudinal body image (i.e. body attitude in **Figure 3.1** overleaf).

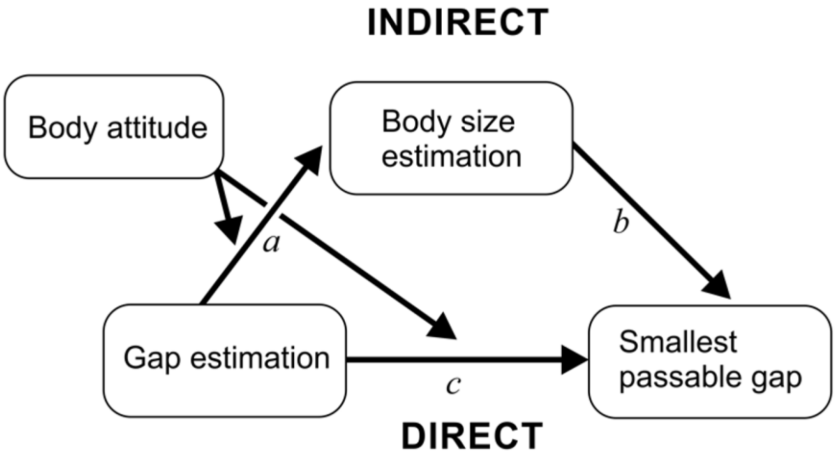

Figure 3.1 *Conceptual form of moderated mediation model.*

The direct path shows how performance in the gap estimation task predicts the size of passable gap. The indirect path shows how this prediction may be partially or fully mediated by perceptual body image (i.e. body size) judgements with the extent of the mediation being moderated by attitudinal aspect of body image.

Broadly speaking, therefore, we aimed to use information about three internal mental states/representations (assessed by the psychophysical and psychometric tasks), to predict an objective, external truth: the smallest gap between two doors into which a front facing participant could fit. To test these predictions required fitting a moderated mediation model. The goal of such models is to empirically quantify and test hypotheses about the contingent nature of the mechanisms by which X (predictor variable) exerts its influence on Y (outcome variable), and therefore they are directional (Hayes, 2015). Often with such analyses it is helpful to have an explicit temporal order for the events being modelled, for example from a longitudinal design, in order to match the directionality inherent in the model. Here, although the timeframe is tight, we suggest that this constraint of temporal order is (to some extent) met because participants need to predict when the sliding doors, which are constantly moving, will match the smallest gap they could walk through.

3.2 Method

The experimental procedures and methods for recruitment and data collection for this study were approved by the Faculty of Health and life Sciences Ethics Committee at Northumbria University.

3.2.1 Participants

To be eligible to take part in this study, participants had to be female (as assigned at birth), aged 18-35, and fluent in English. Participants with a history of eating disorders were not excluded from the study, but this information was recorded (n = 4). Accordingly, we recruited 100 eligible participants (mean age = 23.35, SD = 4.65) from staff and students at Northumbria University in the UK, all of whom consented to take part in the study. Students were given SONA[1] points for taking part. Participant characteristics are reported in **Table 3.1** overleaf.

3.2.2 Materials

Psychometric and anthropometric measures

To measure the attitudinal component of body image, the participants completed a number of self-report questionnaires that measure body satisfaction (BSQ; Evans & Dolan, 1993), tendency towards depression (BDI; Beck et al., 1996), and attitudes towards body shape, weight and eating (EDE-Q; Fairburn & Beglin, 1994), and self-esteem (RSE; Rosenberg et al., 1965) as described in Chapter 2: General Methods (pp. 59 - 63). Cronbach's alpha for each measure was: RSE α = 0.849; BSQ α = 0.944; EDE-Q; α = 0.946; and BDI α = 0.906, suggesting good internal consistency. Participant questionnaire responses are reported in **Table 3.1**.

[1] SONA is a points system that rewards student participation in studies, accrued points can then be used by the students to recruit participants for their own dissertation projects

Table 3.1. Descriptive statistics for age, actual BMI, questionnaire responses, psychophysical and aperture estimation tasks (n = 100)

	M	*SD*	Range	
			Actual	Potential
Participant characteristics				
Age (years)	22.35	4.65	18.00 – 35.00	
BMI (weight/height^2)	22.97	4.15	15.83 – 38.62	
Depression and self-esteem				
BDI	12.19	8.91	0.00 – 47.00	0 – 63
RSE	18.19	4.30	8.00 – 28.00	0 – 34
Eating and body shape concern				
EDE-Q Eating concern	0.97	0.97	0.00 – 4.20	0 – 6
EDE-Q Restraint	1.44	1.32	0.00 – 5.00	0 – 6
EDE-Q Shape concern	2.59	1.54	0.00 – 6.00	0 – 6
EDE-Q Weight concern	2.03	1.51	0.00 – 5.40	0 – 6
EDE-Q Global	1.76	1.20	0.06 – 4.58	0 – 6
BSQ	44.97	17.20	19.00 – 87.00	16 – 96
Psychophysical performance				
Yes-No (BMI units)	23.82	4.38	16.02 – 41.50	
MoA (BMI units)	24.38	5.14	17.03 – 41.86	
Aperture task				
Estimated gap size (cm)	52.64	8.47	31.55 – 87.60	
Estimated ball size (cm)	69.12	8.68	34.80 – 96.10	
Actual passable gap size (cm)	45.78	3.49	39.20 – 59.80	
Estimated – actual gap size (cm)	6.86	7.84	-8.10 – 38.30	

Note: BDI = Beck Depression Inventory , RSE = Rosenberg Self-Esteem Scale, EDE-Q = Eating Disorders Examination Questionnaire with subscales, BSQ = Body Shape Questionnaire

Psychophysical measurements

We used the method of adjustment (MoA), and the method of constant stimuli, in the form of a Yes-No task, as outlined in Chapter 2 in order to estimate participants PSE (perceived BMI).

Body scan measurements

Each participant had a 3D body scan. In a private booth, participants wore only underwear while their body shape was captured using a Size Stream Body Scanner (using scanner software v4.4). This device comprises a set of 14 infra-red depth sensors arranged around the body, each individually fixed to the rigid frame of the booth. Once in the scanner, participants adopted a standard pose while holding hand-rails to steady themselves. They were asked to exhale midway and not to move for ten seconds while the scan was completed. The circumferential inaccuracy of the system, using a test cylinder ~ 880mm tall, is less than +/- 5mm. The data generated by the scan, a large point cloud, were immediately stored off-line by the Size Stream Studio, and software, converted into a 30k polygon mesh from which a large number of biometric measurements are extracted automatically. From the set of outputs available, we selected 8 circumference and limb segment lengths (see **Table 3.2**), together with participants' height and total body volume for further analysis.

The Aperture task

In the current study we used a motor imagery task in which participants were asked to judge the passability of a gap between two sliding wardrobe doors, each measuring 76.5cm x 222cm, viewed binocularly. The doors hung from castors whose wheels ran in tracks mounted on a wooden frame (298cm x 234cm). The doors could be opened and closed smoothly with a pulley system: the left door moved at the same speed as the right door, but in the opposite direction (net separation/closure speed was ~6.72cm/s). White fabric hung 95cm behind the aperture for a uniform background in order to minimize textural cues to aperture size. Participants stood at a fixed distance (2.2m) from the doors, facing them directly, and carried out two conditions: (i) judging when the gap between the doors was just big enough for them to walk through, facing forward ("egocentric gap estimation"), and (ii) judging when the gap between the doors was just big enough for a yoga ball (a control object measuring 58cm in diameter) to pass through without touching the doors ("allocentric ball estimation"). Each condition comprised 20 trials (i.e. 10 door opening trials and 10 door closing trials) and the order of conditions and trials within conditions was randomised. On each trial, the doors were either slowly opened or closed at the fixed rate by the pulley system. Participants were instructed to call out "stop" when they judged that the gap was just wide enough for them to walk through without turning their body or shoulders. A laser distance finder was used to measure the width of the gap between the two doors and this value recorded and the mean gap across 20 trials recorded as the passability judgement for that condition.

The minimum gap through which each individual could physically pass (smallest passable gap) was measured at the very end of the testing session so as not to bias any other perceptual tasks; participants stood between the sliding doors, facing forward, with arms relaxed and hanging down at their sides. The doors were then closed and micro-adjusted until each door was just touching the skin corresponding to the smallest gap in the coronal plane that participants could just pass through. See **Figure 3.2** below for a photograph of the door.

Figure 3.2 *The door used in the aperture task*

3.2.3 Procedure

Participants began by completing the questionnaires, after which height and weight were measured, then the 3D full body scan was obtained. This was then followed by the study's tasks; the order in which the Aperture, MoA and yes-no tasks were completed was fully randomised.

3.2.4 Statistical analyses

Body scan data

We used the 'Psych' package (v1.7.5) in R 3.4.1 (R Development Core Team, 2008) to carry out a factor analysis with Varimax rotation and maximum likelihood estimation in order to identify significant latent variable(s) in 10 body scan measurements: 8 length and circumference measurements, height and total body volume. Next, we correlated these extracted components with participants' actual BMI and smallest passable gap, expecting to observe sizable correlations with 'mesh' components but not with 'rig' components.

Mediation models

After descriptive statistics we present (moderated) mediation models to formally evaluate the model illustrated in **Figure 3.1** in R 3.4.1 (Michalak, 2016). The mediation analyses were conducted with the 'psych' package (v 1.7.5) with 10,000 bootstraps (Revelle, 2016). The moderated mediation analyses were conducted using Preacher and Hayes (2008) method in 'lavaan' v.0.5-23.0197 (Rosseel, 2012) and also examined the index of moderated mediation (Hayes, 2015). Parameters in the moderated mediation model were estimated via Maximum Likelihood and inference was based on 10,000 bias-corrected bootstrap samples. The variables were centred prior to the moderated mediation analyses and we examine the parameter estimates at the means, as well as +/- 1SD.

3.3 Results

3.3.1 Body image data

We used PROC REG in SAS v9.4 (SAS Institute, North Carolina, USA) to build ordinary least squares multiple regression of estimated BMI (from the yes-no task and MoA task) on actual BMI. In addition, we wanted to control for any influence of psychometric variables (RSE, BDI, BSQ and EDEQ). In order to avoid the possibility of introduction substantial variance inflation, we first checked for evidence of co-linearity amongst the psychometric variables. Across the sample, the Pearson correlations were: BDI and RSE, BDI and EDE-Q, BDI and BSQ, RSE and EDE-Q, RSE and BSQ, EDEQ and BSQ: .65, .38, .42, .41, .45, and .83 respectively. All correlation were statistically significant at $p < .001$. Given these substantial correlations, we therefore used PROC FACTOR in SAS v9.4. (SAS Institute, North Carolina, USA) to carry out an iterated principal factor analysis with rotation in order to identify the significant latent variable(s) in the psychometric data. We then used the factor scores from these latent variable(s) in our statistical models. The Kaiser-Meyer-Olin (KMO) measure of samping adequacy was 0.69 suggesting an acceptable sample, an increased sample size could improve this. One factor had an Eigen values greater than Kaiser's criterion of 1, at 2.58 which explained 64% of the variance. The scree plot showed an inflexion, i.e. Cattel's criterion which also justified retaining one factor. The residual were small, and the overall root mean square off-diagonal residual was .19, indicating that the factor structure explained most of the correlations, an increased sample size could improve this. The factor loading for BSQ, EDE-Q, RSE and BDI were .85, .83, .77 and .75 respectively. This latent variable, referred to as PSYCH, represents a combination of the attitudes thought to contribute to body size disturbance: disturbed attitudies to weight, size/shape, eating, as well as low self-esteem and depression.

Next we used PROC REG in SAS v9.4 (SAS Institute, North Carolina, USA) for yes-no task and MoA task. The fixed effects in each model included: BMI and PSYCH, we also tested a model with interaction terms.

Yes-no

The first model for yes-no task explained 58% of variane in estimated BMI and showed statistically significant main effects for BMI (β = .67, t = 9.44, p < .001) and PSYCH (β = .27, t = 3.86, p < .001).

The second model with interaction terms for yes-no task explained 58% of variance in estimated BMI and showed statistically significant main effect of BMI (β = .67, t = 9.38, p < .001), but not PSYCH (β = 1.12, t = .69, p = .49), nor interaction BMI*PSYCH (β = -.003, t = -0.04, p = .96).

Adding the interaction effect between BMI and PSYCH does not contribute meaningfully to the predictive ability of the regression. There was no significant change in R^2, F(1, 95) = 0, p = .96.

MoA

The first model for MoA task explained 66% of variane in estimated BMI and showed statistically significant main effects for BMI (β = .91, t = 12.05, p < .001) and PSYCH (β = 1.04, t = 3.31, p < .001).

The second model with interaction terms for MoA task explained 66% of variance in estimated BMI and showed statistically significant main effect of BMI (β =.90, t =11.93, p < .001), but not PSYCH (β = -1.31, t = -.70, p = .48), nor interaction BMI*PSYCH (β = .10, t = 1.28, p = 20).

Adding the interaction effect between BMI and PSYCH again does not contribute meaningfully to the predictive ability of the regression. There was no significant change in R^2, F(1, 96) = 1.64, p = .20.

Both of these results replicate the findings of Cornelissen et al. (2015) who showed that body size was predicted by a linear combination of perceptual and attitudinal body image.

3.3.2 3D body scan data

The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy (which indicates the degree of diffusion in the pattern of correlations) was 0.81 suggesting an acceptable sample. Two factors had an Eigen value greater than Kaiser's criterion of one, and they explained 79% of the variance. The scree plot showed an inflexion, i.e. Cattel's criterion which also justified retaining two factors. Parallel analysis and the Velicer MAP test also suggested two factors as illustrated in **Figure 3.3** below.

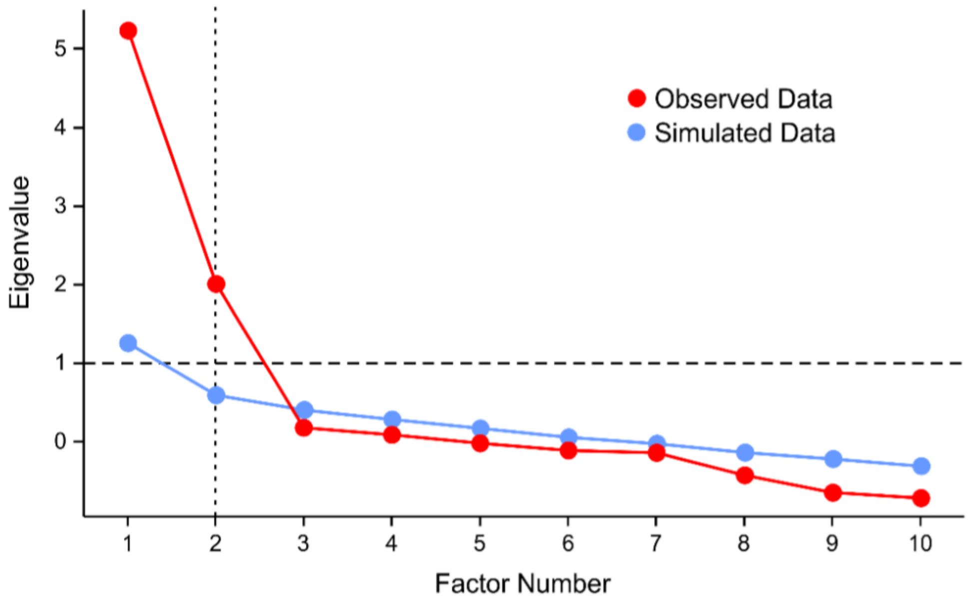

Figure 3.3 *Scree plot including parallel analysis. Factors 1-2 have larger eigenvalues based on the observed data than when based on simulated data*

The overall root mean square off-diagonal residual was 0.04, indicating that the factor structure explained most of the correlations. The factor loadings are shown in **Table 3.2**, and we have blanked out values less than 0.4 for clarity. Factor 1 loaded primarily onto circumference measures, and is referred to as mesh. Factor 2 loaded primarily onto lengths, and is referred to as rig.

Table 3.2. Factor loadings from a factor analysis with rotation of the 3D body scan data (<.4 not shown)

	Factor 1 (Mesh)	Factor 2 (Rig)
Chest bust circ.	0.91	
Waist abdomen circ.	0.90	
Hip circ.	0.90	
R arm bicep circ.	0.86	
R leg thigh circ.	0.87	
Total volume	0.97	
R inseam leng.		0.93
R arm leng.		0.75
R leg leng.		0.83
Height		0.85

NB Circ. = circumference; Leng. = Length; R = Right

Table 3.3 shows the correlation matrix between the two factors and participants actual BMIs as well as the smallest gap (actual gap) they could pass through. It confirms that these two measures were both substantially and significantly correlated with the factor representing horizontal “mesh” circumferences, but not with the latent variable representing “rig” limb segment lengths. (Note that the 95% confidence intervals for the correlations between BMI and Factors 1and 2, and the smallest passable gap [actual gap] and Factors 1 and 2 did not overlap with one another). These findings are important, because they confirm that both perceptual body size and body schema judgements are related to body features that vary primarily in terms of adipose tissue and muscle mass and not the length of limb segments.

Table 3.3. Pearson correlations between participants' actual BMI, actual gap and the two factors. Values in square brackets indicate 95% confidence interval for each correlation

Variable	BMI	Actual gap	Factor 1 ("Mesh")
Actual gap	.76**		
	[.65, .84]		
Factor 1 ("Mesh")	.96**	.79**	
	[.93, .97]	[.70, .86]	
Factor 2 ("Rig")	-.11	.24*	.02
	[-.32, .10]	[.03, .43]	[-.20, .23]

Note: * = p <. 05; ** = p <. 01; *** = p <. 001; 95% C.I. in square brackets

3.3.3 Mediation models

The model in **Figure 3.1** was tested first for mediation alone with *both* yes-no task and MoA as mediators. The total variance explained by this model was 53%. There was evidence of significant mediation (*ab* path: 0.27, 95% C.I.: 0.12 to 0.41), whereby the direct path, c, from gap estimation to passable gap, was substantially reduced from $\beta = .38$ to $\beta = .11$, after accounting for the mediators via the indirect path (see **Figure *a*** in **Appendix A).**

Quantitatively this means that a shift of 8.47cms (one SD) in gap estimation predicts a shift of 1.33cm in actual shoulder width, of which 0.94cm is attributable to the psychophysical tasks. To be sure that we were fitting an optimal model at this stage, we also compared a mediation model in which the positions of passable gap and gap estimation were swapped, so that path c in **Figure 3.1** now had passable gap pointing to gap estimation. This alternative model only explained 18% of the total variance and showed no evidence of mediation (see **Appendix A** for details). This alternative model represents a substantially poorer fit to the data; it explained one third as much variance as the model in **Figure 3.1**. Therefore, it was rejected as a viable alternative.

Sequentially testing the yes-no task and MoA, rather than combining them into a single model showed that each acted as a mediator, respectively, 95% C.I.s: 0.11 to 0.36 and 0.1 to 0.4. Substituting participants' gap estimation based on their own body for yoga ball (control object) estimation, showed no significant mediation effect, respectively: 95% C.I.s: -0.16 to 0.16 and -0.14 to 0.24 (see **Appendix B** for further details). This suggested that any mediation effects we observed were specific to body representations.

Body image as a moderator & mediator

Next, we tested whether body image concern (i.e. the average of BSQ and EDE-Q scores) moderated the relationship between gap estimation and passable gap, i.e. the DIRECT path in **Figure 3.1**. There was no evidence for such a moderation (β = .002+/-.004, $t(96)$ = -.493, p = .623).

Following that, we tested whether body image concern moderated the mediation effects (i.e. the INDRIECT path) of the yes-no task and MoA. In both cases, we found no overall evidence for moderated mediation across the full range of body image concern (respectively: index of moderated mediation: 0.002 +/- 0.003, Z = .586, p = .558 and index of moderated mediation: 0.004 +/- 0.004, Z = 1.03, p = .303).

However, in both cases, we did find that in the 1SD above group, i.e. those with high body image concern, there was evidence for an indirect effect via yes-no task/MoA respectively (yes-no task: β = 0.088 +/- 0.038, Z = 2.336, p = .019, 95% C.I.: 0.014 to 0.164; MoA: β = 0.104 +/- 0.05, Z = 2.098, p = .036, 95% C.I.: 0.011 to 0.209) . In contrast, in the remaining groups (means, 1SD below) there was no evidence for such indirect effect, p's>.12). This suggests that the mediation effect is driven by those with higher body image concern as opposed to lower body image concern, consistent with Keizer et al. (2013); see **Figure 3.4** red circles for BI).

Depressive symptoms as a moderator & mediator

Next, we examined if depressive symptoms (BDI) moderated the relationship between gap estimation and actual gap (i.e. the DIRECT path). There was no evidence of such moderation (β = -.001 +/-. 005, $t(96) = -.195$, $p = .846$).

We then tested moderated mediations (i.e. the INDIRECT path) separately for the yes-no task and MoA task, with depressive symptoms (BDI) as moderator. In both cases we found no evidence for moderated mediation, i.e. depressive symptoms did not change the level of mediation (respectively: index of moderated mediation: 0.002 +/- 0.005, $Z = .398$, $p = .690$ and index of moderated mediation: -0.006 +/- 0.005, $Z = -1.011$, $p = .312$).

However, with the yes-no task, the mediating paths were of roughly equal strength and statistically significant across the three levels of depressive symptoms (all $p < .05$, see **Figure 3.3,** green triangle for BDI), i.e. this is equivalent to saying that strong mediation occurred irrespective of the level of depressive symptoms.

With MoA, the mediating paths were statistically significant for those with low (-1SD) and average depressive symptoms ($p < .01$), but not for those scoring high on depressive symptoms (+1SD) ($p = .209$, see **Figure 3.3**, green triangles for BDI).

Self-esteem as a moderation & mediator

When examining self-esteem (RSE), we found that it moderated the relationship between gap estimation and passable gap (β = -.027 +/- .012, $t(96) = -2.33$, $p = .022$). A simple slope analysis showed a positive slope for those low in self-esteem (one SD below the mean, β = .237 +/- .051, $p < .0001$), but not for those high in self-esteem (one SD above the mean, β = .003 +/- .077, $p = .97$).

We tested moderated mediation separately for the yes-no task and MoA, with self-esteem as moderator (i.e. INDIRECT pathway). We tested the moderated mediations separately for the yes-no task (index of moderated mediation: -0.032 +/- 0.012, $Z = -2.742$, $p = .006$) and MoA task (index of moderated mediation: -0.024 +/-

0.012, Z = -1.982, p =.047); see **Figure 3.4**, blue squares for RSE). The mediating paths were statistically significant for those with low (-1SD) and average scores of self-esteem (all $p < .05$), but not those with high self-esteem (+1SD) (all $p > .4$, see **Figure 3.4**). This suggests that the overall mediation pattern is driven by those with lower self-esteem as opposed to those with higher self-esteem.

In conclusion, in our sample of one hundred typical, healthy women, we found evidence for the perceptual body image mediating performance in an imaginary action, but only for those participants with low self-esteem and raised body image concerns.

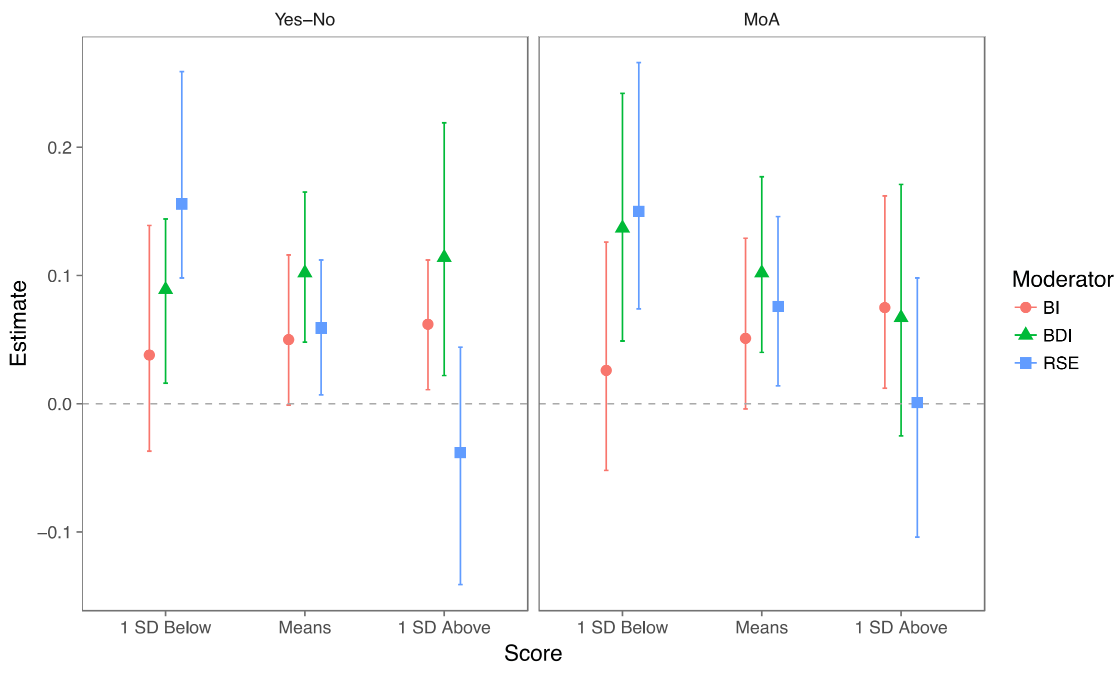

Figure 3.4 *Plots of the beta weights for the indirect pathway (a x b) in the moderated mediation models. The data are shown separately for models with the yes-no and MoA tasks as mediators and the three moderator variables: BI in red circles, BDI in green triangles, and RSE in blue squares at +/- 1SD and their respective means. The error bars represent 95% C.I. and are based on bias-corrected accelerated bootstrapping (10,000 bootstraps), hence their asymmetry.*

Accuracy versus strategy?

The moderated mediation analysis showed clear evidence of individual variation, and by implication, evidence of interaction between representational levels. However, it is not clear from this analysis whether these individual differences gave rise to variation in task accuracy, or variation in individual strategies that participants brought to the tasks, or both. If individual differences in performance are related primarily to variation in task accuracy, then we might expect to see correlations between accuracy in the gap estimation task and the MoA as a function of actual passable gap size. However, if individual variation is related primarily to strategic differences in the attempt to achieve consistent performance, for example, then we should not expect to see such correlations.

To address this, we calculated percentage error in the MoA and gap estimation tasks for every trial as follows:

(MoA BMI – actual BMI) / actual BMI x 100,

and gap estimation:

(estimated gap – actual passable gap) / actual passable gap x 100.

Note, we did not include the yes-no task in this analysis because it is linked to a task depended contraction bias effect, as described in the Introduction (Cornelissen et al., 2017), which would mean that percentage error in this task and actual passable will always be correlated, therefore we would never be able to detect a null relationship.

We used PROC MIXED in SAS v9.4 (SAS Institute, North Carolina, USA) to predict percentage error from: (i) task (i.e. MoA versus Aperture task) and (ii) actual passable gap size in a linear mixed effects model. We included both participants and individual trials as random effects for the intercepts in the model. We found a significant main effect of Task ($\beta = 9.04$, $F(1,3624) = 455.5$, $p < .001$, 95% C.I. = 8.21 – 9.87), but no effect of passable gap size ($\beta = -0.093$, $F(1,3624) = 0.09$, $p = .76$, 95% C.I. = -0.70 – 0.52), nor any interaction between the two. **Figure 3.5** overleaf shows very clearly that participants' errors in the two task were independent of passable gap size. The LSmeans[2] for percentage error for the Aperture task were: 14.24% (95% C.I. = 11.92 – 16.56) and for MoA task: 5.20% (95% C.I. = 2.89 – 7.52).

In short, participants systematically over-estimated both their body size in the MoA task, by about ~5% (consistent with Cornelissen et al., 2017, 2015), and the actual passable gap in the Aperture task by ~15%, as if they had all achieved close to the same criterion level for each task, yet neither pattern of over-estimation was related to actual passable gap.

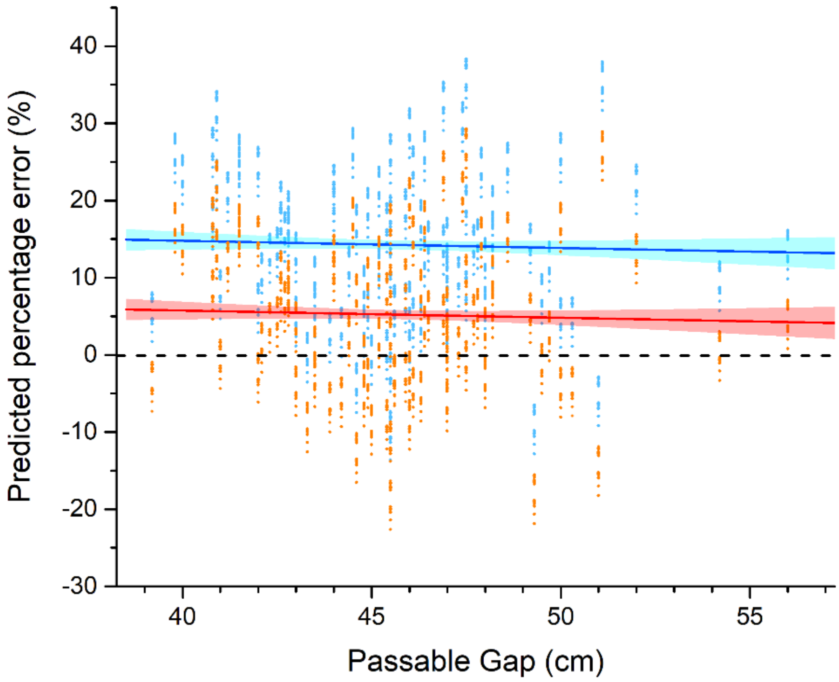

Figure 3.5 *Plots of the predicted percentage error in the gap estimation task (dark cyan dots with blue regression line) and MoA task (orange dots with red regression line) as a function of passable gap size. In each case the regression lines are accompanied by their 99% confidence intervals.*

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[2] Typically means are average computations of the sum of all data divided by the total of number of data points; while LSmeans can be defined as a linear combination (sum) of the estimated effects (means, etc.) from a linear model. These means are based on the model used. In cases where the data has no missing values, the results of the means and LSmeans are identical.

Therefore, these results suggest that the moderated mediation analysis should be best interpreted to reflect variation in the strategies that participants used to achieve criterion performance, rather than variation in accuracy *per se*. Specifically, individuals with high self-esteem and low body image concerns could predict the passable gap size directly – they needed no other information, to achieve a given level of performance. Conversely, individuals with low self-esteem and raised body image concerns appeared to use a combination of the direct estimate of gap size and a distorted estimate of current body metrics in order to achieve the same criterion.

3.4 Discussion

In the general Introduction we discussed evidence to suggest that the internal representations of the body can be separated into at least two general levels: body image and the body schema. Body image underlies perceptual and attitudinal judgements about the body and is a cognitive representation that integrates stored knowledge and experiences. The body schema is a holistic representation which is used to control movement and is constructed primarily from proprioceptive input (Gallagher, 1986; Paillard, 1999, 1991). Here, inspired by observations from patients with eating disorders (Cornelissen et al., 2015; Keizer et al., 2013), we investigated how these two body representations may interact in a healthy female population, at least in one particular context, that of making imagery 'affordance' judgements. We asked healthy adult women to judge the smallest gap they could just pass through between a pair of sliding doors. We then asked whether these estimates were sufficient to predict the size of the smallest gap that they could *actually* pass through (passable gap), or whether additional information from their attitudinal and/or perceptual body image was required in order to make these predictions.

Our first aim was met, as we replicated Cornelissen et al. (2015), and showed that perceptual body image judgments, indexed by BMI, were predicted by a linear combination of participant's actual BMI and their attitudes about their body shape and weight. In the context of the main research question, our analysis of the 3D body scan data also confirmed that judgements about body image and the passability of gaps are related only to those body shape components belonging to the horizontal properties of the body “mesh” and not the vertical properties of the “rig”. This finding is important empirically because it explicitly links body image (as indexed by BMI), gap estimation and actual passable gap size to a common and specific subset of body shape measures: those which are highly associated with changes in adiposity and muscle mass (Wells, Cole, Bruer, & Treleaven, 2008; Wells, Treleaven & Cole, 2007).

Finally, our moderated mediation analysis suggested that a complex pattern of interdependence between these representational domains exist, because perceptual body image information was required to predict smallest passable gap size, it had a mediating role, but only for those individuals who have self-reported to have elevated concerns about their body shape and/or those with reduced self-esteem. Moreover, these interactions are specific to self-referential egocentric judgements about the body, because no such inter-relationships could be found for equivalent allocentric judgements made for an inanimate object, i.e. a yoga ball.

The implications of these findings are two-fold. Firstly, these results suggest that it may only be individuals without higher psychological concerns about body shape/ weight and normal levels of self-esteem who are able to update current body state information to guide movement of the body, as is usually conceived. For those who have such concerns, it appears that the strength of the emotional salience or valence of the false beliefs about their over-sized body (or more specifically, body parts that are more susceptible to large and/or rapid changes in adiposity/muscle mass) which accompany these concerns serves a moderating purpose. It moderates the degree to which this distorted perceptual body image is weighted when determining the current body-state or prevents sensory/proprioceptive/kinaesthetic information from updating the stored body representation used by the body schema for programming egocentric body movement. The second implication is that apparently anomalous behaviour of women with anorexia nervosa reported by Keizer et al. (2013) is not qualitatively different from that seen in otherwise healthy women who happen to have higher self-reported body image concerns and low self-esteem.

Previous research has demonstrated interactions between body image and affective states, such as self-esteem (Hoffmeister, Teige-Mocigemba, Blechert, Klauer, & Tuschen-Caffier, 2010), as well as with pain, which has both separable nociceptive and cognitive/emotional components (Woo, Roy, Buhle, & Wager, 2015). For example, having induced the rubber hand illusion (RHI), Ehrsson et al. (2007) showed that threats of pin pricks to a rubber hand could induce neural patterns of anxiety which were very similar to those measured for threats to a real hand. Moreover, the magnitude of these neural responses was correlated with the strength of participants' ownership of the hand. In patients with chronic hand pain, Moseley, Parsons, and Spence (2008) showed that visual distortion of the body image, modulated both the level of pain experienced, and the extent of tissue swelling evoked by movement. Impressively, these effects were bi-directional. Optical magnification of the limb increased pain and swelling, while minification reduced them. Finally, Schwoebel et al. (2001) asked participants with chronic unilateral arm pain to decide on the laterality of images of hands presented at different orientations. Reaction times in this imagery mental rotation task, were systematically slower for the painful arm compared to the unaffected arm, consistent with pain having an influence on the body schema. Finally, the defensive peri-personal space, or 'safety margin' surrounding the body which Moseley et al. (2012) suggest is maintained by the same 'body matrix' that integrates homeostatic, somatotopic and body-centred spatial information, has also been shown to be influenced by affective state; individuals reporting higher train anxiety scores also demonstrate larger safety margins for the same stimuli (Sambo & Iannetti, 2013; de Vignemont & Iannetti, 2015).

In short, there have been previous reports of emotionally valent stimuli having an influence on, or being influenced by, either the body image or the body schema. However, outside of the clinical domain, to our knowledge the current study is the first time that interactions between the body schema, perceptual body image and, critically, attitudinal body image have been observed and quantified.

Beyond neurological and neuropsychological studies of patients, task dependent effects on bodily illusions have previously supported the notion that body schema is functionally separable from the body image (Kammers, van der Ham, & Dijkerman, 2006). For example, during the rubber hand illusion (RHI) (Botvinick & Cohen, 1998), participants are shown a rubber hand that has the same posture and orientation as their own visually occluded hand, but which is displaced medially or laterally with respect to their own hand. When the rubber hand and the participant's hand are stroked synchronously, the participant experiences a multisensory conflict of seeing a touch that is felt at a different location. The conflict is resolved through a perceptual shift whereby the felt position of the participant's own hand appears to migrate towards that of the rubber hand. This is thought to occur through a process of visual capture, whereby proprioceptive information encoded earlier in time is over-written by current visual and tactile information, and the rubber hand is incorporated into the participants' own body image (Ehrsson, Spence, & Passingham, 2004; Ehrsson, Holmes, & Passingham, 2005). In contrast, if participants are also asked to make ballistic pointing movements to indicate the positions of the unseen simulated and non-simulated finger tips, their performance is very accurate (Kammers, de Vignemont, Verhagen, & Dijkerman, 2009), and it was suggested that these movements, thought to be supported by the body schema, are refractory to the RHI, and therefore dissociable from responses dependent on the body image.

Clearly, it is possible to use short-term experimental manipulations of bodily illusions in healthy participants to provide results that mirror the findings from patients. However, in more recent research, Kammers et al. (2010) have demonstrated that the body schema can also be influenced by the RHI if the amount of stimulation of the participant's hands and the rubbed hand is manipulated, and hand postures are changed to facilitate grasping rather than pointing. Under these circumstances, manipulating the grip aperture of the rubber hand leads not only to a perceptual illusion (body image distortion) but also altered grasping responses (body schema distortion). A similar result was also reported by Newport, Pearce, and Preston (2010) using a digitally presented real-time version of the RHI to induce the illusion of supernumerary limbs. Participants were able to incorporate multiple representations of the same limb into the body image, and when an offset representation of the hand was seen to stroke a paintbrush synchronously with the unseen real hand, pointing errors revealed a remapped limb position in which the perceived real hand location was remapped towards the location of the offset limb; the illusion also affected body schema.

Such studies demonstrate that body image and body schema are not as 'dissociable' as initially thought, although these short-term intervention studies do not demonstrate how the two systems may normally be expected to interact with each other in the steady state, over the longer term, and this was the focus of the current study. Moreover, what may be revealed in the short-term as a result of experimental manipulation may not necessarily hold true for the long term. Indeed, an increasing number of studies and reviews have suggested that there are direct inter-relationships between differing representations of the body, and that there may in fact be a common long-term representation underlying body action *and* bodily experiences (e.g. Alsmith, 2009; Berlucchi & Aglioti, 2010, Bermudez, 2005; Moseley et al., 2012; de Vignemont 2010). Pitron and de Vignemont (2017, p.116) discuss this singular 'fusion' model, and compare it to two alternatives. The first, the 'independent model', posits "…two distinct functionally defined representations of the enduring properties of the body, a long-term body schema for action and long-term body image for perception, that work independently of each other". The second, the 'co-construction model', proposes "… two distinct functionally defined representations of the enduring properties of the body, a long-term body schema for action and long-term body image for perception which can interact and reshape each other". Pitron and de Vignemont (2017) argue the case for a Bayesian version of the co-construction model, and we would argue in turn that such an interaction model is a good fit to our current findings, with the addition of a moderator role for attitudinal body image. Further, we would suggest that the putative mechanisms responsible for the distortions observed in both the body image and body schema of individuals with EDs may be the inability to fully integrate current sensory input that is in conflict with a distorted long-term representation that hold higher emotional/affective salience.

Following a similar line of argument, dissociations between the body schema and body image have been claimed based on illusions induced by tendon vibration (Goodwin, McCloskey, & Matthews, 1972). Tendon vibration to the biceps creates an illusory lengthening of the muscle which leads to the perception of limb displacement, in this case elbow extension. Using this illusion, Kammers et al. (2006) asked participants either to: (i) reach with their non-vibrated (left) arm and point to their fingerprint on the stimulated (right) arm, indexing possible body schema distortions, and (ii) match the position of the non-simulated forearm to the felt location of the stimulated forearm, indexing possible body image distortion. Kammers et al. (2006) found that forearm position matching judgements were much more susceptible to tendon-vibration than reaching movements. In short, body image processing could again be dissociated from the body schema. It is worth noting that in more recent research by Kammers et al. (2010) demonstrated that the body schema can also be influenced by the rubber hand illusion, if the amount of stimulation of the participants' hands and the rubber hand is manipulated, and hand posture changed to facilitate grasping rather than pointing. Under these circumstances manipulating the grip aperture of the rubber hand leads not only to a perceptual illusion (body image distortion) but also altered grasping responses (body schema distortion).

A central assumption of Study 1 was that the gap estimation task indexes the body schema because it can be treated as a visuomotor imagery task: participants need to predict when the sliding doors, which are constantly moving, will match the smallest gap they would have to walk through. In support of this assumption, there are several lines of evidence demonstrating that the same cognitive/neural representations are used for motor imagery and motor execution. For example, there is substantial overlap between the brain areas that are activated by both actual and imagined movement (Bakker et al., 2008; Hanakawa et al., 2003; Roth et al., 1996), even in patients with complete spinal cord injury (Alkhadi, Brugger, Boenderkamer et al., 2005). With a human-computer interface, motor imagery can be used to drive a computer cursor, for example, with neural signal strengths matching those of real motor execution (Miller et al., 2010). Furthermore, studies of patients with parietal cortex lesions (Sirigu et al., 1996) and healthy controls in virtual reality (Decety et al., 1995) have shown that the durations of imagined and actual movements are constrained in similar ways by the timing and accuracy requirements of the tasks that participants performed (Guardia, 2012). However, it should be noted motor imagery and motor execution cannot be considered entirely equivalent: conditional Granger causality and graph-theoretic analyses of fMRI data revealed greater causal connection for execution than imagery, suggesting wider network involvement for the former (Gao, Duan & Chen, 2011). Nevertheless, it appears that motor execution and motor imagery have sufficient kinematic properties and neural processes in common (Hesslow, 2012) for us to assume that the gap estimation task is a valid and appropriate way to assess body schema integrity (Guardia et al., 2012).

From an empirical point of view, if the aperture task cannot be treated as a motor imagery task, then the only realistic alternative would be to consider it as a third way for participants to estimate their body size as part of their perceptual body image. If this were true, then the gap estimations would be equivalent to the yes-no and method of adjustment tasks; they would all, in effect, be proxies for each other. If this was the case, then it should not matter for the mediation analysis whether gap estimates are the main predictor, and the yes-no / method of adjustment task the mediator, or vice versa, (i.e. the roles of mediator and predictor should be interchangeable). We therefore sought evidence of mediation for this ‘reversed’ mediation model which had either the yes-no task or method of adjustment as the main predictor for actual gap size and gap estimation as the mediator variable in these relationships. However, there was no statistical support for either case: i) yes-no task as predictor, gap estimation ab path: 0.04, 95%CI: -0.005 to 0.15, and ii) method of adjustment task as predictor, gap estimation ab path: 0.03, 95%CI: -0.002 to 0.10. Furthermore, if anticipatory gap estimation were merely another form of perceptual size estimation task, we would also expect to see size errors of a similar magnitude between the two tasks, but this is not the case. Errors on the motor imagery (gap estimation) task were three times the size of those seen in the PSE tasks, which is in keeping with previous literature examining the difference between depictive and metric methods of body-size estimation (e.g. Longo & Haggard, 2012; Mölbert, Klein, Thaler et al., 2017). We believe that this lack of symmetry, and the fact that it is not possible to use the mediator and predictor variables interchangeably within the mediation model, taken together with the literature reviewed above, is consistent with the view that our aperture task can legitimately be treated as a motor imagery task to index the body schema.

Additionally, we asked participants to judge the passability of a yoga ball in the aperture task in order to independently assess participants' accuracy in the aperture task using a non-body-related stimulus for purely allocentric judgements that prevented comparisons with another bodily exemplar, and to provide a 'baseline' of gap estimation ability for the mediation models. Our prime concern was to exclude the possibility that individual variation in gap estimates might be attributable to some generic process making some people more accurate than others in all psychophysical tasks. To the extent that the yoga ball and gap estimation data were dissociated from each other, we can confidently exclude a generic error mechanism as a strong confound in the results. However, as we did not include a further allocentric, body-related, condition, then strictly speaking, inferences cannot be made as to whether our findings (or those of Guardia et al., 2010 and Keizer et al., 2013) relate specifically to participants' own bodies, or their perception of bodies more generally. Nevertheless, the results of Guardia et al. (2012), in which participants were asked to make passability judgements for both themselves and a third person, suggest that body overestimation affects judgments about the capacity for action only when they concern the individual's own body.

In conclusion, we demonstrated that information purported to be related to perpetual body image influences performance on a simulated motor task. Moreover, the degree to which this information is co-opted when solving egocentric (but not allocentric) motor imagery tasks, such as judging the smallest passable gap one can fit through, is contingent upon individual difference variables relating to body image concerns and reduced self-esteem. This has important implications for the treatment of eating disorders, and future work would benefit from experimentally manipulating these domains separately.

Chapter 4: Investigating key body areas used to estimate body size, studies 2, 3 and 4

This series of studies investigated the key body areas used to estimate body size using an adapted Bubbles paradigm. In this paradigm, the stimuli is occluded with a mask interrupted by randomly allocated Gaussian “windows” which reveal parts of the stimuli, therefore forcing judgements to be made based on this partial information. A total of 72 women took part in 3 studies. In studies 2 and 3 the distinction between central versus edge featural information was investigated, and the visual features used in body judgements were localised. In study 3, eye-movements were measured in conjuction with the bubbles paradigm, and the results of the two techniques were mapped onto a common reference space.

4.1 Introduction

As described in Chapter 1, the Introduction, the mis-estimation of body size is a key feature of both anorexia and bulimia nervosa (Cash & Deagle, 1997; Cornelissen, Johns, & Tovée, 2013; Fernández-Aranda et al., 1999; Gardner & Bokenkamp, 1996; Hagman et al., 2014; Hamilton & Waller, 1993; Mohr, Zimmermann, Röder, & Lenz, 2010; Probst, Vandereycken, Van Coppenolle, & Pieters, 1998; Probst, Vandereycken, Van Coppenolle, & Pieters, 1995; Roy & Forest, 2007; Slade & Russell, 1973; Tovée, Benson, Emery, Mason, & Cohen-Tovée, 2010). It is also the most persistent of all eating disorders symptoms and plays a central role in treatment difficulties and relapse (Berkman et al., 2007; Casper et al., 1979; Channon & DeSilva, 1985; Sala et al., 2012). To address the estimation problem, it is important to understand the visual cues that are used to judge body size, and how the misjudgement of body size arises. The current chapter addressed the question of which image features drive judgements of body size?

Visual cues to body size judgements

Previous studies have suggested two potential sets of cues that may drive these judgements; firstly, the width of the body, and secondly, the cues within the body outline. The first set of cues are straightforward. Previous studies have noted that the width of the torso increases with increasing body mass index, particularly around the waist region. (e.g. Cornelissen et al., 2009; Tovée et al., 1999; Tovée & Cornelissen, 2001). This "thickening" of the torso could therefore provide an index of body mass. The second set of cues are internal to the body outline. These include the saliency of body landmarks, such as collar bones and ribs, which become more obvious and visible as body fat declines (George, Cornelissen, Hancock, Kiviniemi, & Tovée, 2011). Additionally, as the amount of body fat increases, it is deposited across the body, e.g. as rolls of fat, whose size and quantity could be used to estimate total body mass.

In support of the first hypothesis, a principle component analysis (PCA) of images of female bodies varying in BMI, but facing forward in a standard pose, found that the change in torso width was described by principle component 1 (PC1), and this factor was the main predictor of body judgements (Tovée et al., 2002). Additionally, when the results of this PCA were used to create a set of artificial bodies, simply varying PC1 was sufficient to drive the perception of body weight change without any of the other shape dimensions (Smith et al., 2007a). This suggests that simple changes in torso width are sufficient to drive the perception of body mass.

This result is also consistent with a recent study which varied body orientation relative to the observer (Cornelissen et al., 2018). The observers had to discriminate between pairs of bodies in a 2-alternative forced choice task based on differences in BMI. The finest discrimination occurred for the bodies presented either in profile or at 45° relative to the observer, and the worst discriminations occurred when the bodies were presented in front-view (Cornelissen et al., 2018). Most pertinently, the sensitivity of discrimination was predicted by the magnitude of the torso width change detectable by the observer. As BMI increased, the degree of change in torso width as a proportion of the total torso width, is greater in profile or at 45° than in front-view. This is true for both CGI bodies and digital photographs of real bodies (Cornelissen et al., 2018). As a result, judgements in profile or at 45° tend to be more accurate than those made in front-view. This difference in performance and its correlation with the saliency of the visual cues to torso width change, suggests that this is the cue that is being used to judge body size.

Alternatively, there are also visual cues that are internal to the body outline that index overall body mass, and several studies suggest that in practice these are the cues being used with making body size judgements. The evidence for this hypothesis is primarily based on eye-movement studies. For example, women with anorexia nervosa have been found to fixate more on these body landmarks, e.g. collar bones and ribs, when making body size judgements than control observers, and were significantly better than control observers at judging the body size of low weight bodies (Cornelissen et al., 2015; George et al., 2011; Hewig et al., 2008). This suggests that the use of these cues may form the basis of a successful strategy in judging lower BMI bodies. Additionally, as mentioned the amount of fat increases, it is deposited as rolls of fat, which can also be used to estimate body mass. Between these extremes, the pattern of texture gradients across the surface of the body can potentially provide a cue to the 3D shape of the body, such as size of the stomach (Cornelissen et al., 2013; Tovée, Hancock, Mahmoodi, Singleton, & Cornelissen, 2002).

Several studies have suggested that stomach size, indexed through its depth, as a strong cue to BMI (Rilling et al., 2010; Smith et al., 2007; Tovée et al., 1999). Eye-movement data suggests that control participants who were accurate at estimating their own BMI, fixated primarily on the stomach, with these fixations falling *within* the body outline (Cornelissen et al., 2016b; 2009; George et al., 2011). This was true whether the observers were judging bodies seen in front-view or at 45° angle. If observers were simply viewing the degree to which the stomach protrudes then their fixations should shift between central fixations on the torso in front-view, to fixations on the edge body outline in 45° viewing angle. However, the fixations remained centrally located

(Cornelissen et al., 2016b; George et al., 2011; Cornelissen et al., 2009). This is surprising, as if participants were asked to judge torso shape, they made eye-movements across the body and sequentially fixated on either size of the torso edge (Cornelissen et al., 2009). This suggests that when viewing bodies at a 45° angle, the optimal fixation strategy for estimating stomach depth would be to make fixations on both edges of the body corresponding to its outline. However, under these viewing conditions, observers whose fixations were not concentrated centrally (within the body outline) and those who looked more at the edges of the body, were less accurate in their body mass judgements (Cornelissen et al., 2016b). This suggests that the principal cues being used to judge body mass are located within the body outline.

However, a potential key flaw with these eye-movements studies is the assumption that visual attention is always aligned directly with the line of sight. It has been suggested that this may not necessarily be the case as attention shifts are not necessarily related to saccadic eye-movement systems as suggested by a number of studies (e.g. Ehinger & Rosenholtz, 2016; Gegenfurtner, 2016; Datta & DeYoe, 2009; Posner, 1980; Posner, Snyder, & Davidson, 1980). For example, in judgements of a basketball scenario, a contingent-gaze paradigm suggested that the position of the player with the ball was used as an “anchor point” for an observer’s fixation while the relative position of the other players was estimated using the peripheral visual field (Ryu, Abernethy, Mann, Poolton, & Gorman, 2013). Thus, a particular fixation point may just be a suitable point in the visual field from which to sample visual information using the retinal periphery, and not the complete focus of an observer’s attention. This then raises an alternative possibility that in the eye-tracking studies on body size estimation, it is possible that instead of extracting information within the body outline the eye-movement pattern is actually an efficient foraging strategy which allows a wider attentional window to extract edge-based cues on the torso using a central looking strategy.

It is well-known that resolution acuity (i.e. the smallest separation between two points that allows them to be seen as separate) drops off dramatically from the central fovea towards the parafovea and beyond (Anderson, Mullen, & Hess, 1991; Carrasco, 2011, Pelli, & Tillman, 2008). This necessarily means that the apparent sharpness of the torso edges when sampled by a strategy of viewing the centre of the body would be reduced; put simply, they would appear blurry. However, it is important to remember that the visual system's ability to resolve edge alignment, edge sharpness or smoothness and curvature, i.e. exactly the kind of low-level features that are likely to be needed to estimate the separation and shape of the torso edge, operate within the hyperacuity range (Carrasco, 2011). The phenomenon of hyperacuity is based not on the cone density of the retina, but on cortical calculation which extrapolates from the limited sampling away to estimates a more detailed percept (Motter & Belky, 1998; Gegenfurthen, 2016). This means that these spatial attributes can potentially be resolved to an accuracy often an order of magnitude finer than that of resolution acuity, even in the presence of a blurred stimulus. Therefore, there is no reason in principle why a foraging strategy that appears to blur the edges of the object being judged will impair the visual system's ability to discriminate the locations and shapes of those edges in calculating body size.

A potential way of disambiguating these two possibilities: i.e. edge versus central image information and gauging the location of the attentional window during a perceptual judgement of body suze is the bubbles masking technique (Gosselin & Schyns, 2001). It is a psychophysics paradigm that has been used to determine which visual cues are being used in categorisation task. The stimuli is masked, and parts of it are revealed by randomly allocated Gaussian "windows", observers attempt to make a judgement base on this partial information. Over multiple trials, all potential cues are sampled and from this unbiased sampling strategy, it is possible to calculate how effective each Gaussian window was at independently determining the behavioural performance (Humphreys, Minshew, Leonard, & Behrmann, 2007). Thus, it should be possible to localise the areas of a body stimulus that are actually used when participants make self-estimates of body size and their relative importance.

This technique, however, has its own potential flaw. It is possible that the imposition of the bubble masks fundamentally changes the looking strategy (Gosselin & Schyns et al., 2004; Murray & Gold, 2004). Therefore, we address this problem by using an adapted bubbles strategy which emphasises the distinction between central versus edge featural information (studies 2 and 3). Additionally, in study 4, we also measured eye-movements to test whether the underlying search strategy, reflected in eye fixation patterns, has changed from the up and down in the middle of the body fixation strategy reported by previous studies of self-estimation of body size estimation.

Here we ask what visual cues to participants use when judging their own body size? The literature reviewed, suggests that there are two potential sets of cues that participants could be using to make these judgements: information about the separation of the torso edges, and information about body shape containted within the body outline If the former case is true, we should espect to find a dissociation between where participants look on the stimulis bodies and the location of the regions on the bodies that are diagnostic for body size. Specifically, we predict that the eye fixations should lie along the vertical midline of the body stimuli, and the diagnostic regions should lie along the left and right torso edges. If, however, the latter case is true, both the diagnostic regions and the eye fications should be spatially coincidenta, and both should be aligned with the vertical midline o the stimulis body.

All the studies were completed by two sets of observers. In a pre-test screening process, we identified observers who were accurate at estimating their own body size, and observers who were inaccurate. By using both accurate and inaccurate observers, we were able to compare the features important for an accurate judgement with the regions which lead to a mis-estimation.As discussed above, over-estimation of body size in women with anorexia nervosa is thought to arise from either one or both of two factors; attitudinal or perceptual distortion. By testing non-clinical samples who over-estimate body size compared to those who are accurate at estimating body size and who have the same psychological concerns, we can focus purely on perceptual factors as the basis of the overestimation. Ultimately, we intend to extend this research to compare diagnostic regions for self-estimates of body size in people wih eating disorders with those from accurate and over-estimating individuals without eating disorders. However, those studies make heavy demands on participants. Therefore, as a first step in the introduction of the bubbles paradigm into this research area, we felt it appropriate to recruit participants who had no history of eating disorders.

4.2 Method: Study 2 – Big bubbles

The experimental procedures and methods of participant recruitment for this study were approved by the Northumbria University ethics committee.

Participants

Pilot testing showed that the maxima and minima in the group differences in correctly responding in diagnostic areas that were biologically meaningful (e.g. edge of torso, central abdomen, and gap between thighs) could be detected using a sample size of between 4 and 11 participants per group, (alpha = 0.05 and power = 80%). To offset attrition in participant numbers and/or unexpected sources of variability, we therefore recruited 12 participants per group.

To be eligible to take part, participants had to be female (as assigned at birth), aged 18-35, with no history of eating disorders, and they had to have normal or corrected to normal vision. Accordingly, 41 females were recruited from the staff and students at Northumbria University, who carried out the initial psychometric and psychophysical tests. Body size over-estimators were defined as those participants whose point of subjective equality (PSE) from the yes-no task was at least 2 BMI units above their measured BMI. Accurate body-size estimators recorded a PSE within +/-1 BMI unit of their measured BMI. Following these criteria, 12 accurate size-estimators and 12 over-estimators were identified from the initial sample of consenting women and invited to complete the full study. The characteristics of these participants are reported in **Table 4.1**.

Materials

Psychometric and anthropometric measures

To measure the attitudinal component of body image, the participants completed a number of self-report questionnaires that measure: body satisfaction (BSQ, Evans & Dolan, 1993), tendency towards depression (BDI, Beck et al., 1961), and attitudes towards body shape, weight and eating (EDE-Q, Fairburn & Beglin, 1994), as described in Chapter 2: General Methods (pp. 59 - 63).. Cronbach's alpha for each measure was: BDI α = 0.92; BSQ α = 0.95; and EDE-Q α = 0.94.

Participants' Body Mass Index (BMI) was calculated from their weight and height measured with a set of calibrated clinical SECA scales and a stadiometer respectively.

Psychophysical measurements

We used the method of constant stimuli, in the form of yes-no task, as outlined in Chapter 2: General Methods, in order to estimate participants' perceived size (in BMI units). Participants were classified as accurate at body size estimation if their PSE was within +/- 1 BMI unit of their measured BMI, and over-estimators if their PSE was > 2 BMI units above their measured BMI.

Bubbles task

We built a bubbles masking task that was inspired by, but different from, the Bubbles paradigm developed by Gosselin and Schyns (2001). In these authors' task, like ours, on every trial, participants are given a partial view of a stimulis through a set of Gaussian windows (i.e. circular holes with blurred edges, see **Figure 4.1**). the windows are punched, as it were, through a gray overlay that covers the stimulus image. In Gosseling and Schyns (2001), the centre of any one Gaussian bubble can be located at any poxel location in the stimuls image. However, in the current study, a more directed question was asked: whether the information from the edges of the body outline, or the midline of the body primarily drive decisions about self-estimates of body size. For this reason, the bubble locations were constrained to three columns (see **Figure 4.5** for grid outline, and **Figure 4.1** for examples of 2 trials).

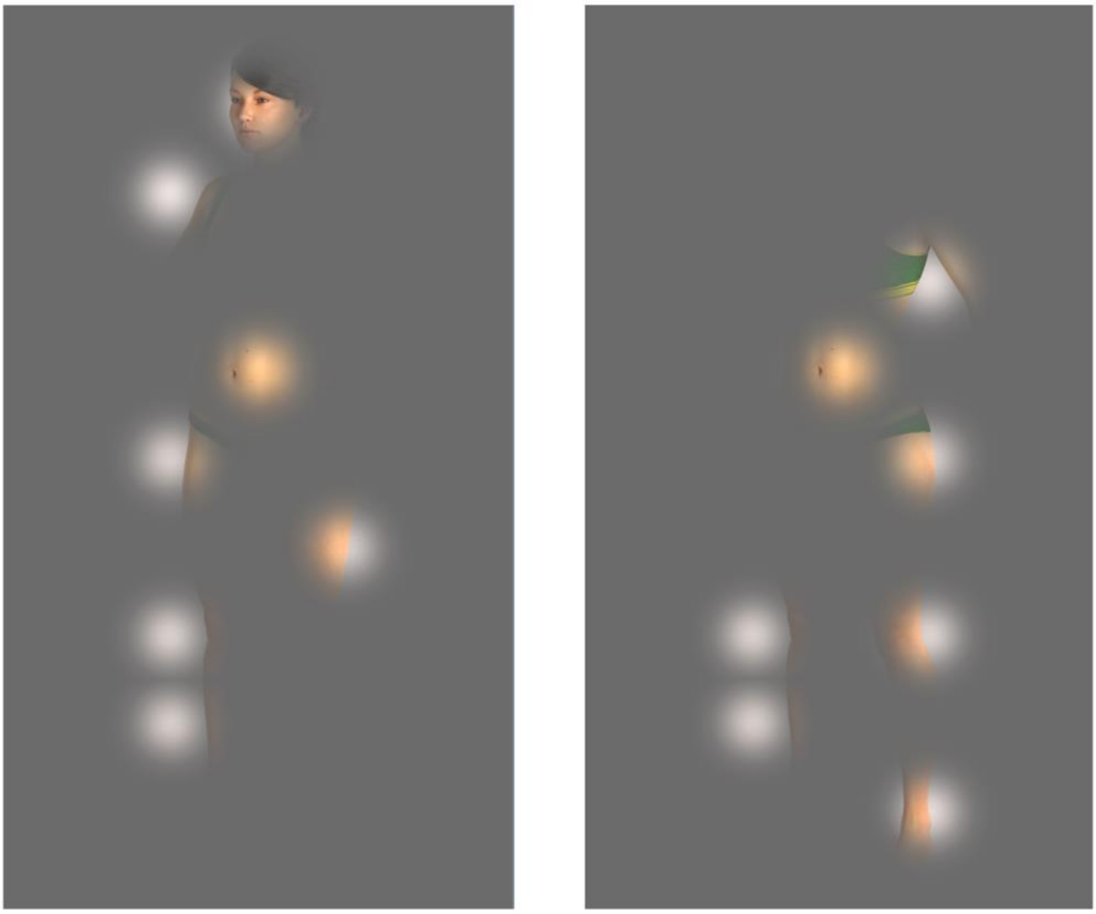


Figure 4.1. *Shows examples of two trials from study 2 with big bubbles.*

The bubbles in the left column of the stimulus overlay the right body edge and allowed the participants to see this edge only (note, here we use the anatomical convention where left refers to the left side of the person in the stimulus image, from their point of view). Bubbles in the middle column overlay the midline of the body in the stimulus image, therefore restricting participants' view to the midline of the body only. Bubbles in the right column overlay the left body edge (**Figure 4.1**). This approach meant that we could carry out a spatial analysis of percentage correct responses at each fixed bubble location, and explicitly test for differences in body size classification between bubbles in the midline versus the two edge columns.

Bubbles were created dynamically as the program ran the task. On each trial, a stimulus image was covered by a grey mask (RGB: 64, 64, 64 on a 0-256 range), punctured by bubbles, whose centres were defined by the centres of an invisible, rectangular grid of squares 3(w) x 9(h), corresponding to the three columns (left edge, middle, right edge); the layout of bubbles on the gridlines is visible in **Figure 4.5**. Each square of the grid measured 100 x 100 pixels. In study 2, the transparency of the bubbles followed a 2D Gaussian distribution with a standard deviation of 0.56 degrees. On each trial of the task, a subset of the bubble locations was randomly chosen from the 3 x 9 array to make the masked stimuli visible, and participants had to decide, and respond by button press, whether the underlying image (drawn from the same stimulus set a the yes-no task) was larger or smaller than the participant believed themselves to be. Half of the images presented were larger, and half of them smaller than the participant. The particular pair of images presented to each participant were chosen based on their difference limen (DL) in the yes-no task. The smaller image corresponded to the 25% response rate in the yes-no task and the larger image to the 75% response rate. The image presentation was randomised. Like Gosselin and Schyns (2001), we sought to maintain participants' performance in the task at ~75% correct across the 2000 trials of the task. To do this, we calculated the correct response rate after every 20 trials, and reduced the bubble count by 1, kept it the same or increased it by 1, depending on whether the participant's responses were below, at or above criterion (within +/- 15%), the task began with 3 bubbles available.

Procedure

Having read the information sheet, the participants gave written consent. To maximise participants' vigilance and minimise their fatigue, they typically completed the study over the course of 3 sessions on 3 consecutive days. On the first day, the participants' height and weight were measured, then in a quiet, private testing room they completed the psychometric questionnaires, and completed the yes-no task. This session took approximately 40mins. The participants who were eligible to complete the full study, i.e. those who fit our criteria for accurate or over-estimation of body size, carried out the bubbles task over the next two sessions, each of which lasted up to an hour. Trials were presented back to back, each new trial triggered by the participant's button response. A pause was included after every 140 trials, giving an opportunity for a break. Once all the tasks were completed, participants were verbally debriefed, given the opportunity to ask questions and provided with a debrief sheet.

4.3 Results: Study 2 – Big bubbles

Univariate statistics

Table 4.1 describes the participant characteristic from study 2. The right-hand columns of **Table 4.1** show the output of pairwise comparisons of the two group means, adjusted for multiple comparisons, using the permutation method in PROC MULTEST (SAS v9.4, SAS Institute, North Carolina, USA). **Table 4.1** confirms that accurate estimators were within ~0.25 BMI units of their actual BMI, on average, as compared to over-estimators who over-estimated by ~4 BMI units. With respect to the World Health Organisation (WHO, 2003) classification scheme, the numbers of participants who fell into the under-weight, normal, over-weight and obese categories for the accurate and over-estimating groups, were: 0, 11, 1, 0 and 1, 9, 2, 0, respectively. The mean BSQ scores shown in **Table 4.1** are consistent with mild concern with body shape (Evans & Dolan, 1993). The mean BDI scores for the accurate and over-estimating groups are both consistent with the mild range. The EDE-Q subscales in both groups all fall within 1SD of the normative means for women within this age group (Mond et al., 2006).

Table 4.1. Study 2 participant characteristics: big bubbles

	Accurate (*n*=12)		Over-estimate (*n*=12)		Accurate v Over-estimate
	M	*SD*	*M*	*SD*	*p*
Participant characteristics					
Age (years)	23.67	5.65	22.25	4.37	.99
BMI (kg/m^2)	21.97	2.89	22.16	3.22	1.00
Depression					
BDI score	15.17	9.84	17.75	11.28	.99
Body shape and eating concerns					
BSQ score	38.92	20.78	47.67	23.03	.91
EDE - Q global score	1.32	1.02	2.23	1.57	.50
EDE - Q res score	1.40	1.37	2.03	1.32	.86
EDE - Q eat score	0.45	0.52	1.28	1.42	.35
EDE - Q wc score	1.58	1.45	2.47	1.84	.76
EDE - Q sc score	1.86	1.67	3.14	2.17	.55
Psychophysical performance					
PSE (kg/m^2)	22.16	2.98	25.85	3.40	.07
DL (kg/m^2)	0.67	0.26	1.15	0.88	.43
Over-estimation (PSE – BMI)	0.19	0.78	3.69	1.31	<.001
Mean bubble count	5.00	1.08	5.12	1.21	.92
Mean percentage trials correct	74.41	0.86	74.33	1.10	.97

Note: BDI = Beck Depression Inventory, BSQ = Body Shape Questionnaire, EDE - Q = Eating Disorders Examination Questionnaire global score, and EDE-Q subscales: res = restraint, eat = eating concerns, WC = weight concerns, SC = shape concerns

Where are the diagnostic regions for the accurate and over-estimating groups?

In study 2, on each trial, the stimulus to be judged was masked, and only visible through the bubbles picked at random from an array of 3(w) x 9(h) bubble locations. By the end of that task, the number of times that any particular bubble location had been used, as well as proportion of those presentations that were associated with a correct response were recorded for each participant. Therefore, a percentage correct could be calculated for every bubble location, separately for each participant.

The adaptive procedure ensured that participants' responses tracked close to the criterion that was set for the masking task, namely that 75% of the choices they made across 2000 trials should be correct, and **Table 4.1** confirms this. To achieve this criterion performance, both groups required on average a bubble count of ~5 bubbles (see **Table 4.1**). As Gosselin and Schyns (2001) argue, if all regions in our stimuli were equally informative about body size, then the proportion of correct responses at each location in our mask array should match the same criterion: i.e. the response rate for every bubble location should also be 75% correct. However, if there is a subset of areas in the stimulus that are particularly informative about body size, then one should expect the response rates in bubbles overlying these regions to be significantly higher than 75%. Such areas should correspond to regions that are diagnostic of body size, according to the terminology of Gosselin and Schyns (2001). However, for this to be true, and for average performance across the set of trials to be 75% correct, we should also expect the response rates in bubble locations that overlie non-informative regions in the stimuli to be lower than 75% correct.

To test these predictions, we ran three generalized linear mixed models (GLMMs) of the normalised percentage responses across different bubble locations, using PROC MIXED in SAS v9.4 (SAS Institute, North Carolina, USA). To normalise the data, we calculated the mean percentage correct across all 3(w) x 9(h) bubble locations for each participant, and then subtracted these global means from the percentage correct for each individual bubble location, separately for each participant. For spatially sampled data, we cannot assume that the percentage correct responses at each bubble location are statistically independent of each other. Specifically, we must assume that percentage correct will co-vary across bubble locations, and that the magnitude of this spatial co-variation is inversely proportional to the bubbles' proximity to each other. Therefore, in all three models we took account of the repeated measures within subjects, i.e. each subject was presented 27 mask locations in all (defined by the row and column co-ordinates). In addition, spatial co-variance was controlled by incorporating the spatial variability into the statistical models by specifying a Gaussian spatial correlation model for the model residuals (Littel et al., 2006). The general form of the model we fitted was:

$$E[Y|u] = X\beta + Zu + e$$

Where $E[Y|u]$ is the conditional probability of the outcome given the random model effects. $X\beta$ are the fixed effects, Zu are the random effects and e the error term.

Spatial correlation was reflected in R, the covariance matrix of the model errors. The fixed effects in all models comprised three class variables: ROW (i.e. the index for each row of the grid of bubbles, which could take values 1 to 9 inclusive), COLUMN (i.e. the index for each column of the grid of bubbles, which could take values 1 to 3 inclusive). This means that the location of each bubbles in the 3x9 mask array was uniquely addressed, like and *x, y* coordinate, by the combination of the two fixed effect variables, ROW and COLUMN. Where relevant, we also included GROUP (i.e. accurate body size estimators versus over-estimators) as a fixed effect when we wanted to compare performance between accurate body-size estimators versus over-estimators. The most important outcomes from the statistical modelling were to identify:

MODEL 1: Where were the areas diagnostic of body size (i.e. > 75% correct) for accurate estimators?

MODEL 2: Where were the areas diagnostic of body size (i.e. > 75% correct) for over-estimators?

MODEL 3: Where were the significant differences in diagnostic areas for body size comparing accurate with over-estimators?

To do this, for each model, we computed the predicted population margins from the GLMMs and compared them using tests for simple effects by partitioning the interaction effects, controlling for multiple comparisons. In other words, for MODELS 1 and 2, we used the fitted GLMMs to predict the percentage of correct responses in each bubble location and asked whether that percentage was significantly greater than 75%. These predictions are corrected for the repeated measures design, the spatial covariance in the data and the fact that we carried out multiple comparisons. For MODEL 3 we used the fitted GLMM to predict the difference in the percentage of correct responses comparing accurate body size estimators and over-estimators and asked whether each of these differences was significantly different from zero. An additional constraint for MODEL 3 was that a bubble location was only deemed to show a statistically significant difference between accurate and over-estimators if that location had a response rate significantly greater than 75% ($p < .01$) from either MODEL 1 or MODEL 2, as well as showing a significant group difference. For completeness, we report the fixed effects in each model below, and then show the key outcomes, i.e. the predicted percentages of correct responses in each bubble location in **Figure 4.1**.

The Type III tests of fixed effects for **MODEL 1** were: ROW $F(4,44) = 1.04$, $p = .40$; COLUMN $F(10,110) = 25.02$, $p < .001$; ROW x COLUMN $F(40,440) = 5.19$, $p < .001$.

The Type III tests of fixed effects for **MODEL 2** were: ROW $F(4,44) = 0.27$, $p = .90$; COLUMN $F(10,110) = 12.98$, $p < .001$; ROW x COLUMN $F(40,440) = 7.37$, $p < .001$.

The Type III tests of fixed effects for **MODEL 3** were: GROUP $F(1,22) = 0.00$, $p = .99$; ROW $F(4,88) = 0.23$, $p = .92$; GROUP x ROW $F(4,88) = 1.16$, $p = .33$; COLUMN $F(10,220) = 36.91$, $p < .001$; COLUMN x GROUP $F(10,220) = 2.39$, $p = 0.01$; ROW x COLUMN $F(40,880) = 10.28$, $p < .001$; GROUP x ROW x COLUMN $F(40,880) = 2.05$, $p < .001$.

In principle, a significant fixed effect of ROW means that, averages across columns, there would be a signficaint linear increase/decrease in percentage correct responses as a function of ROW – i.e. a tilt to the 2D regression plane. Similarly, a significant fixed effect of COLUMN would mean that, averaged across rows, there would be a significant lincrease/decrease in percentage correct responses as a function of COLUMN. A significant interaction between ROW and COLUMN would mean that the degree of tilt in the 2D regression plane with respect to ROW, say, changes as a function of COLUMN. As the foregoing description of the fixed effects in the GLMMs makes clear, it is encouraging that we see statistically significant interactions between ROW and COLUMN in all three models. This strongly suggests that there are indeed statistically significant diagnostic regions of interest. However, analysis of the diagnostic bubbles. For this, we need post-hoc comparisons.

The first two columns in **Figure 4.2** show the outcomes from MODEL 1 and MODEL 2, for accurate body size estimators and over-estimators respectively. Circles correspond to mask locations where correct response rates were significantly higher than criterion (i.e. 75%), based on the GLMMs, and which can be therefore considered diagnostic regions. The heat maps (the red/orange/yellow coloured overlay) represent the averaged and smoothed raw data above criterion.

For the accurate estimators, the circles *a* (80.4%, 95% C.I. 79.0 – 81.8%) and *c* (82.0%, 95% C.I. 80.7 – 83.4%) correspond to the peak LSmean response rates for the left and right columns of mask bubbles respectively, and circle *b* (78.4%, 95% C.I. 77.1 – 79.8%) is the closest mask bubble adjacent to both *a* and *c*. Circle *d* (78.4%, 95% C.I. 77.1 – 79.8%) corresponds to the peak LSmean response rate for the central column of mask bubbles. Therefore, while it is true that the central abdomen provides information

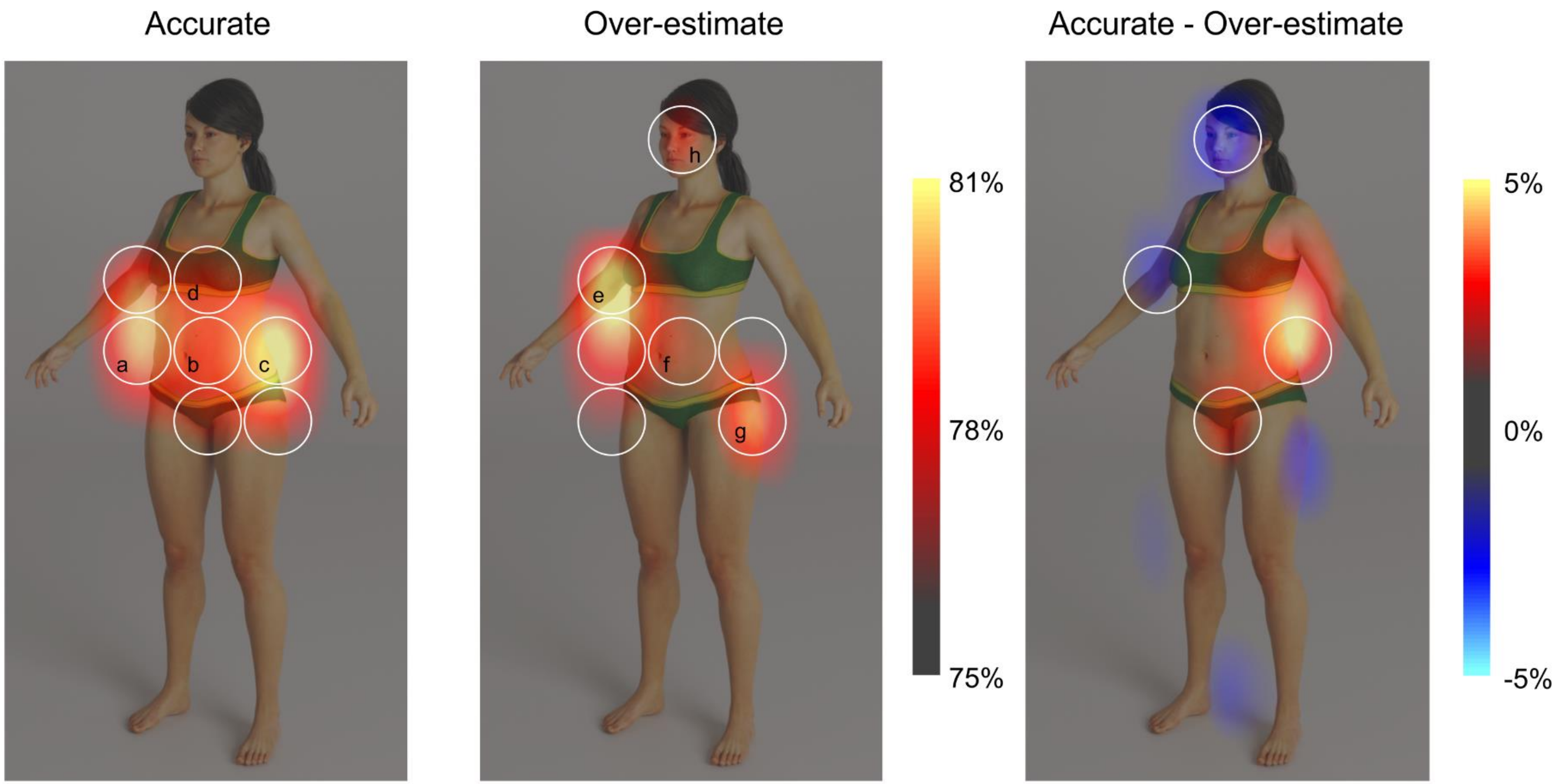


Figure 4.2. *Diagnostic images for the big bubbles study. For the Accurate and Over-estimate figures (left and middle columns), the white circles show the locations of bubbles where correct response rates were significantly above the 75% criterion based on the GLMMs. The heat maps represent the averaged and smoothed raw data that contributed to the GLMMs. For the Accurate – Over-estimate figure (right column), the white circles show where the differences between the two groups of observers are significantly different from zero. The blue-cyan colours in the heat map show where over-estimators made more correct responses than accurate estimators. The red-yellow colours in the heat map show where accurate estimators made more correct responses than over-estimators.*

that is is diagnostic about body size for accurate estimators, the left and right torso edges appear to provide more information, and this difference is statistically significant for the left torso edge (i.e. the 95% confidence interval for *c* does not overlap with those for *b* or *d*).

For the over-estimators, circles *e* (82.0%, 95% C.I. 80.8 – 83.3%) and *g* (80.2%, 95% C.I. 78.9 – 81.4%) correspond to the peak LSmean response rate for the left and right sides of the torso, and circle *f* (77.1%, 95% C.I. 75.9 – 78.4%) is the closest mask bubble adjacent to both *e* and *g*. Circle *h* (77.9%, 95% C.I. 76.7 – 79.2%) corresponds to the peak LSmean response rate for the central column of mask bubbles. Therefore, unlike the accurate estimators, midline information is providing diagnostic information about the face. As with the accurate estimators, the midline is also providing diagnostic information about the abdomen. However, the upper right torso and the left hip are providivgn more, and this difference is statistically significant for the upper right torso (i.e. the 95% confidence interval for circle *e* does not overlap with those for *f* or *h*).

The right most column in **Figure 4.2** shows where diagnostic information about body size differs significantly between accurate and over-estimators. Specifically, accurate estimators make significantly more use of information from the upper thigh gap and the left edge of the abdomen (red/yellow colours), whereas over-estimators make significantly more use of information from the right upper torso/arm and the face (blue/cyan colours).

4.4 Study 2: Discussion

The results of study 2 suggest the while both groups utilised information from the middle of the body as well as its edges, the edges provided more diagnostic information, i.e. were more instrumental in driving participants' decisions in the categorisation task. Additionally, the two groups differed significantly in the edge cues used. While the accurate estimators made most use of the left flank and thigh gap, the over-estimators used the face and right arm/chest area more. Interestingly, eye-tracking studies suggest that women with anorexia nervosa, who also over-estimate body size, also fixate more on the face than controls who accurately estimate body size (Cornelissen et al., 2016b). Accurate estimators also show a distribution of diagnostic areas that are more evenly spread onto both sides of the body (see left panel of **Figure 4.2**), whereas the diagnostic areas of over-estimators showed a bias onto one size of the torso (see right panel of **Figure 4.2**),

Even though the evidence from study 2 suggests that body edges provided diagnostic information for body size judgements, some mid-body features are still used, i.e. the face and thigh-gap. Therefore, in order to provide a more detailed picture of the edge cues used, the size of the bubbles was decreased from 100 x 100 pixels to 40 x 40 pixels. With this strategy, by providing more bubbles that are smaller in size a more detailed picture of the diagnostic information may be gathered.

4.5 Method: Study 3 – Small bubbles

Participants

The selection criteria and methods of participant recruitment were the same as for study 2. Accordingly, 12 accurate body size estimators and 12 over-estimators were identified from an initial sample of 41 consenting women. The participant characteristics for study 3 are reported in **Table 4.2.**

Materials

The psychometric and psychophysical tasks were identical to study 2. The only difference in the bubble task was that we used a finer scale rectangular grid of 9(w) x 21(h) squares (each of which measured 40 x 40 pixels) to locate the bubble centres. See **Figure 4.3** below for two examples of trials. The transparency of these smaller bubbles followed a 2D Gaussian distribution with a standard deviation of 0.29 degrees, and the bubble count was increased or decreased by 2 bubbles, starting with 15 bubbles when that task begun.

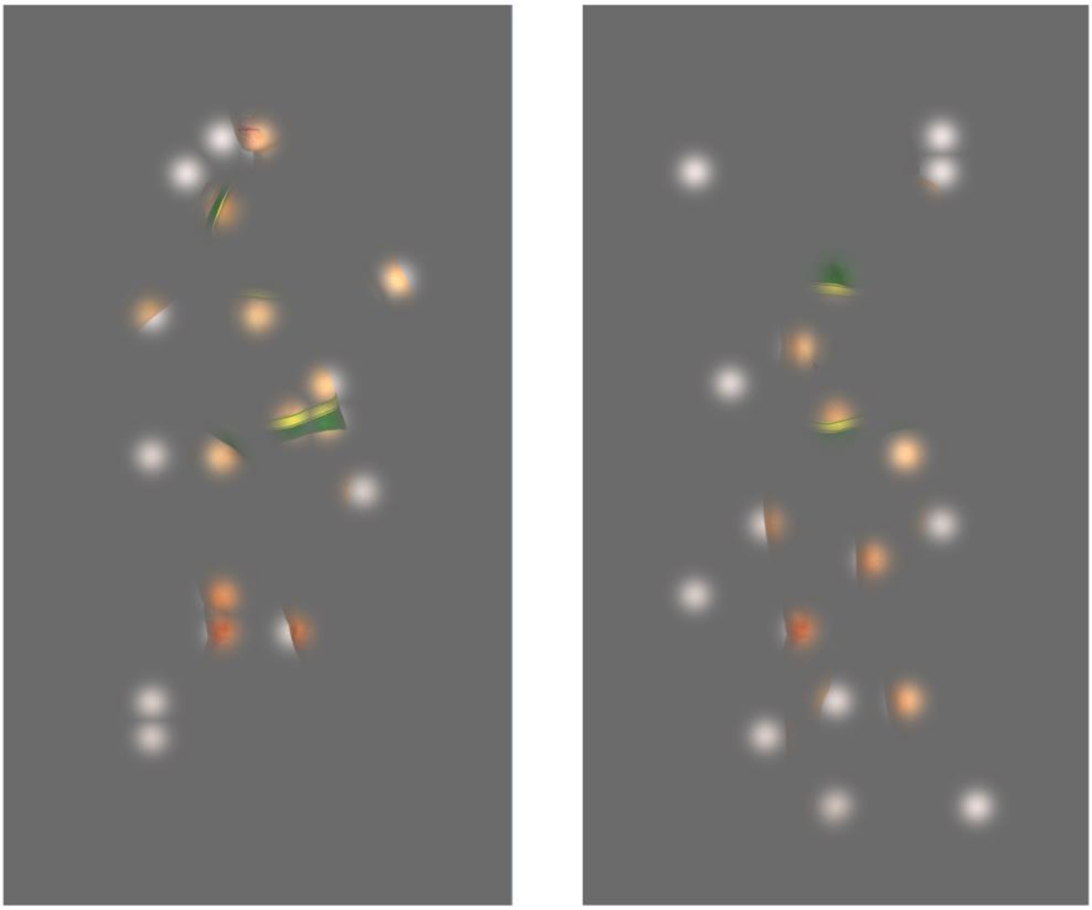


Figure 4.3 *Shows examples of two trials from study 3 with small bubbles.*

Table 4.2. Study 3 participant characteristics: small bubbles

	Accurate (*n*=12)		Over-estimate (*n*=12)		Accurate v Over-estimate
	M	*SD*	*M*	*SD*	*p*
Participant characteristics					
Age (years)	22.58	6.40	20.92	3.75	.98
BMI (kg/m^2)	22.55	4.80	21.99	2.94	.99
Depression					
BDI score	9.50	8.60	16.83	11.34	.45
Body shape and eating concerns					
BSQ score	45.67	23.91	53.17	18.41	.97
EDE - Q global score	1.74	1.66	2.65	1.29	.64
EDE - Q res score	1.35	1.43	2.22	1.43	.65
EDE - Q eat score	1.08	1.48	1.63	1.40	.95
EDE - Q wc score	2.08	2.09	2.97	1.63	.85
EDE - Q sc score	2.43	1.92	3.79	1.39	.33
Psychophysical performance					
PSE (kg/m^2)	22.40	4.68	25.96	2.72	.20
DL (kg/m^2)	.75	.30	1.03	0.23	.11
Over-estimation (PSE – BMI)	-.15	.57	3.97	1.35	<.001
Mean bubble count	18.42	5.51	19.62	3.86	.74
Mean percentage trials correct	74.75	1.46	74.03	1.05	.61

Note: BDI = Beck Depression Inventory, BSQ = Body Shape Questionnaire, EDE-Q = Eating Disorders Examination Questionnaire global score, and EDE-Q subscales: res = restraint, eat = eating concerns, WC = weight concerns, SC = shape concerns

4.6 Results: Study 3

Univariate statistics

Table 4.2 describes the participant characteristics from study 3 and confirms that accurate estimators were within ~0.25 BMI units of their actual BMI, on average, as compared to over-estimators who over-estimated by ~4 BMI units. With respect to the World Health Organization's BMI classification scheme (WHO, 2003), the numbers of participants who fell into the under-weight, normal, over-weight and obese categories for the accurate and over-estimating groups, respectively, were: 0, 10, 1, 1 and 2, 8, 2, 0. Cronbach's alpha for the psychometric tasks BDI, BSQ and EDE-Q in the two groups were 0.92, 0.96 and 0.97, respectively. The mean BSQ scores shown in **Table 4.2** are consistent with mild concern with body shape (Evans & Dolan, 1993). The mean BDI scores for the accurate and over-estimating groups are consistent with the minimal and mild ranges respectively. The EDE-Q subscales in both groups all fall within 1SD of the normative means for women within this age group (Mond et al., 2006). **Table 4.2** shows that the adaptive procedure maintained participant performance very close to 75% correct in both groups, and that they required ~18-19 bubbles on average to achieve this performance.

Where are the diagnostic regions for the accurate and over-estimating groups?

The rationale for the analysis procedures in study 3 were identical to those for study 2, therefore the treatment of data is the same, and we fitted the same 3 GLMMs as in study 2. The only difference was in the resolution of the bubble mask, which comprised 9(w) x 21(h) bubble locations; the layout of bubbles on the gridlines in visible in **Figure 4.5**.

The Type III tests of fixed effects for **MODEL 1** were: ROW $F(10,110) = 10.44$, $p < .001$; COL $F(22,242) = 5.88$, $p < .001$; ROW x COL $F(220,2420) = 2.39$, $p < .001$.

The Type III tests of fixed effects for **MODEL 2** were: ROW $F(10,110) = 15.51$, $p < .001$; COL $F(22,242) = 8.21$, $p < .001$; ROW x COL $F(220,2420) = 3.13$, $p < .001$.

The Type III tests of fixed effects for **MODEL 3** were: GROUP $F(1,22) = 0.00$, $p = .99$; ROW $F(10,220) = 24.7$, $p < .001$; GROUP x ROW $F(10,220) = 1.21$, $p = .28$; COL $F(22,484) = 12.56$, $p < .001$; COL x GROUP $F(22,484) = 1.51$, $p = 0.06$; ROW x COL $F(220,4840) = 4.13$, $p < .001$; GROUP x ROW x COL $F(220,4840) = 1.38$, $p < .001$

As before, the first two columns in **Figure 4.4** show the outcomes from MODEL 1 and MODEL 2, for accurate body size estimators and over-estimators respectively. Circles correspond to mask locations where correct response rates were significantly higher than criterion (i.e. 75%), based on the GLMMs. The heat maps represent the smoothed, averaged raw data above criterion. For the accurate estimators, the bubble locations corresponding to significant diagnostic information about body size are clustered continuously along the edge of the right lower chest and abdomen, the edge of the left waist and upper hip and the thigh gap (again using anatomical conventions for left and right). The over-estimators show a very similar pattern along the right edge of the upper body and a more extensive cluster along the left body edge extending to the chest. However, it appears that the over-estimators do not make use of the thigh gap. The right most column in **Figure 4.4** shows where diagnostic information about body size differs significantly between accurate and over-estimators. Specifically, accurate estimators make significantly more use of information from the upper thigh gap and a small region just to the right of the midline in the upper abdomen (red/yellow colours). In comparison, the over-estimators make more use of information on the right abdominal edge, as well as the left upper quadrant of the abdomen (blue/cyan colours).

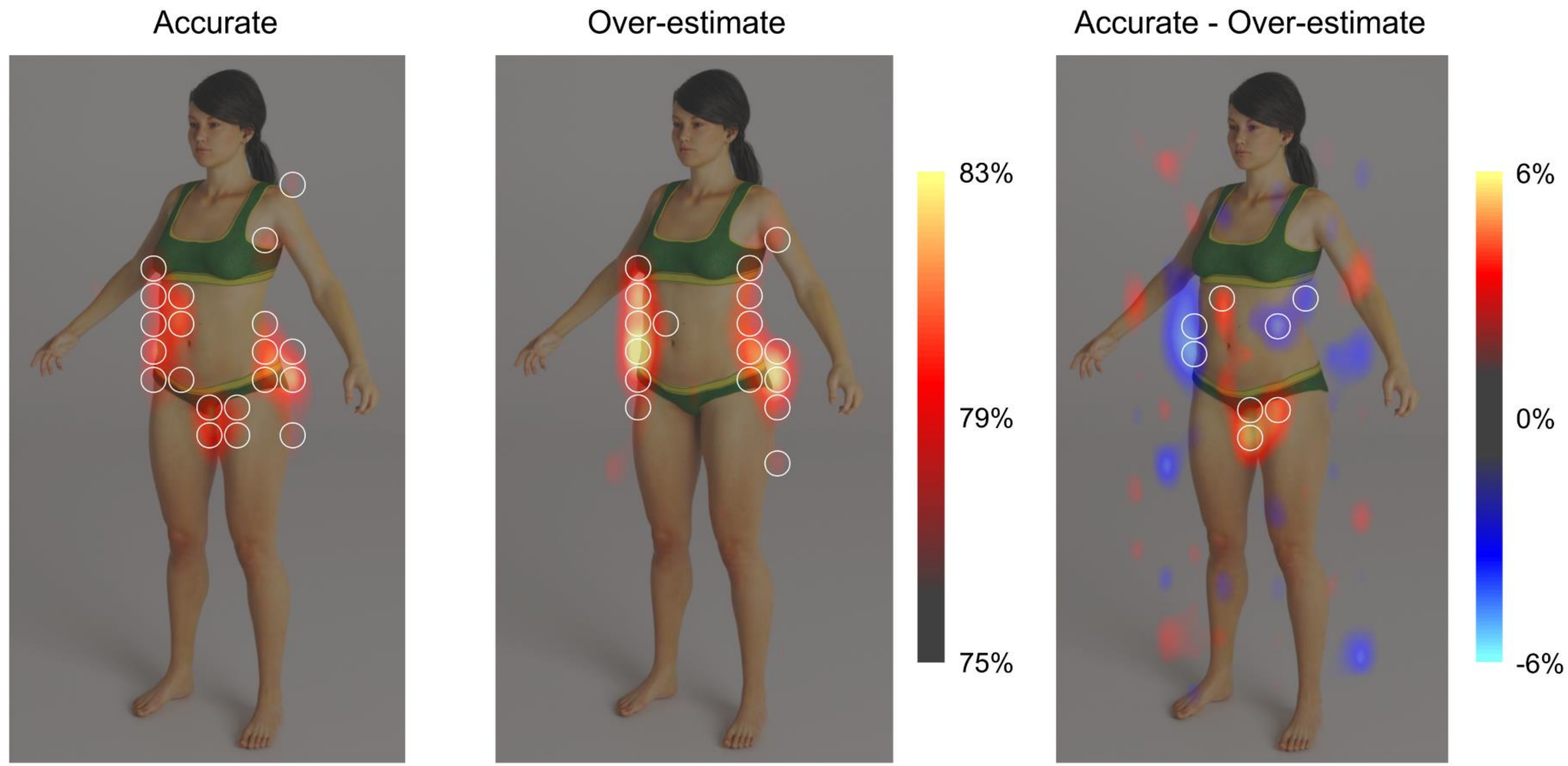


Figure 4.4 *Diagnostic images for the small bubbles study. For the Accurate and Over-estimate figures (left and middle columns), the white circles show the locations of bubbles where correct response rates were significantly above the 75% criterion based on the GLMMs. The heat maps represent the averaged and smoothed raw data that contributed to the GLMMs. For the Accurate – Over-estimate figure (right column), the white circles show where the differences between the two groups of observers are significantly different from zero. The blue-cyan colours in the heat map show where over-estimators made more correct responses than accurate estimators. The red-yellow colours in the heat map show where accurate estimators made more correct responses than over-estimators.*

4.7 Study 3: Discussion

The results of study 3 suggest that for both groups the edges of the body were instrumental in driving self-estimates of body size. Again, the two groups differed in cues used, with accurate estimators using the information about the thigh gap, and a region in the upper abdomen, while the over-estimators used more cues from the right edge of the abdomen and an upper area of the abdomen. These results provide a more detailed picture of the diagnostic areas used driving self-estimates of body size.

However, as described in the Introduction, it is possible that the presence of the bubbles and the partial view of the stimulus that this provides changes the oberver's looking strategy. Therefore, in the next study eye-movements of the participants were measured to identify if the up-down looking pattern reported by prior studies of size estimation changed (Cornelissen et al., 2016b).

4.8 Study 4: Rationale

The next question that needed to be answered was where the participants were fixating when they carried out the bubble mask task with small and large bubbles. Therefore, in a third sample of participants, we recorded the movements of the right eye (without testing for eye dominance) during 200 trials of each version of the bubble mask task. In addition, we also wanted to identify any differences in gaze patterns between the bubble mask task (as carried our in Studies 2 and 3), compared to using the same size bubbles and the same task, i.e. judging whether the presented image was larger or smaller than the participant believed themselves to be, but now with all bubbles always set to transparent (see **Figure 4.5** overleaf). These latter conditions, 200 trials with large bubbles all open and 200 trials with small bubbles all open, were the closest one could get to normal viewing using the bubbles task, and still permitting maximum visibility of all parts of the stimuli simultaneously, on every trial. Given that the view of the body per trial during the actual bubbles mask task is so restricted, we fully expected that there should be greater dispersion of fixations across space, when the data were binned over the course of 200 trials. Nevertheless, the critical question was whether participants adopted a different viewing strategy compared to what is usually seen when participants view non-masked bodies: i.e. looking up and down the midline of the body (see e.g. Cornelissen et al., 2016b). Specifically, given the evidence from Studies 2 and 3 that the body edges provide diagnostic information for self-estimates of body size, we needed to know whether fixation patterns during the bubble masking task also split into two distinct distributions, with their peaks similarly aligned with the left and right body edges, instead of the midline.

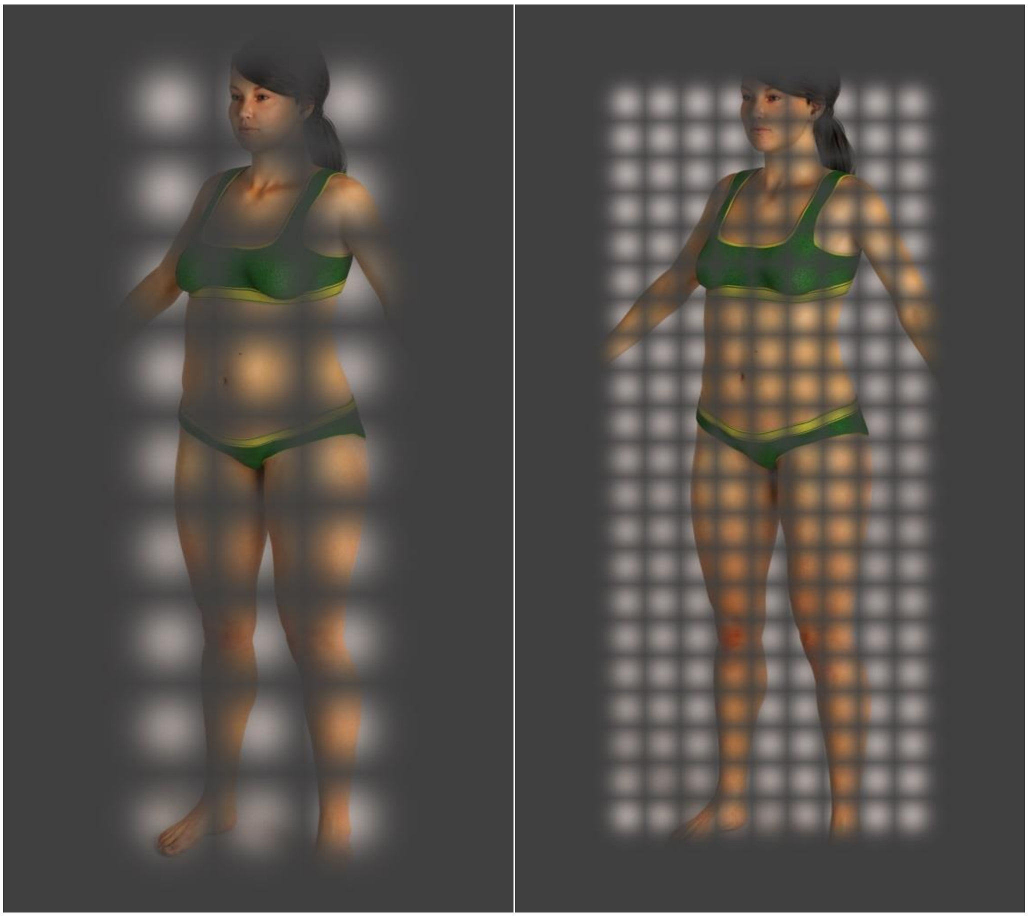


Figure 4.5 *Example stimuli for big bubbles (left panel) and small bubbles (right panel) when all bubbles are set to transparent (i.e. all bubbles open).*

4.9 Method: Study 4 – Eye-tracking

Participants

The selection criteria and methods of participant recruitment were the same as for Studies 2 and 3. Accordingly, 12 accurate body size estimators and 12 over-estimators were identified from an initial sample of 36 consenting women, and were invited to take part in the complete study. The characteristics of these 24 participants are reported in **Table 4.3**.

Measures

The psychometric and psychophysical tasks were identical to Studies 2 and 3.

Eye movement recordings

Movements of the right eye were recorded with an Eyelink 1000 eye-tracker at a sample rate of 1000Hz. Stimuli were presented on a flat 19" CRT monitor while participants sat at a table with their heads restrained by a combined chin and forehead rest. At the standard viewing distance of ~60cm, the image frame containing the female body subtended ~26° vertically and ~8° degrees horizontally. At the start of each block of 200 trials, participants' eye movements were calibrated using a 9-point calibration screen. Once the calibration procedure was validated, the experimental task began. The order of the four versions of masking (large bubbles, large bubbles open, small bubbles and small bubbles open) was randomised across participants. While we did record participants' button responses in the task, there were not enough trials to warrant a spatial analysis of these behavioural data (i.e. 1/10th of the number of trials in Studies 2 and 3). Nevertheless, the average accuracy of responding over the 200 trials for the large bubbles, large bubbles open, small bubbles and small bubbles open was: 69%, 88%, 67 % and 87% respectively for accurate estimators. The equivalent performance for over-estimators was: 69%, 98%, 69% and 96% respectively. Tests of location showed that all these values are significantly better than guessing (i.e. 50% accuracy), even though participants performance had not stabilized at the ~75% criterion, which would be expected had they carried out all 2000 trials of the main tasks.

The Eyelink 1000 system uses a saccade-picker approach to identify saccades by applying an exclusive OR rule to three thresholds: velocity (30 deg/sec), acceleration (8000 deg/sec2) and distance moved between samples (0.1deg). It then treats the rest of the (non-blink) data as fixations, assuming that the ‘not in a saccade’ condition is maintained for at least 50ms. The stated accuracy of the system is down to a resolution of 0.15°, though 0.25° to 0.5° is typical.

Table 4.3. Study 4 participant characteristics

	Accurate (n=12)		Over-estimate (n=12)		Accurate v Over-estimate
	M	SD	M	SD	*p*
Participant characteristics					
Age (years)	20.58	1.98	23.33	5.35	.55
BMI (kg/m^2)	23.42	6.38	21.73	3.57	.98
Depression					
BDI score	12.50	8.12	15.17	8.12	.98
Body shape and eating concerns					
BSQ	38.92	16.81	46.33	12.61	.83
EDE-Q global	1.38	.97	2.15	1.24	.53
EDE-Q res	1.15	.92	2.37	1.89	.33
EDE-Q eat	.65	.69	1.12	.96	.75
EDE-Q wc	1.55	1.48	2.32	1.11	.71
EDE-Q sc	2.16	1.55	2.79	1.35	.91
Psychophysical performance					
PSE (kg/m^2)	23.45	6.15	25.35	3.27	.95
DL (kg/m^2)	.78	.40	.92	.65	.99
Over-estimation (PSE – BMI)	.03	.64	3.62	2.03	<.001

Note: BDI = Beck Depression Inventory, BSQ = Body Shape Questionnaire, EDE-Q = Eating Disorders Examination Questionnaire global score, and EDE-Q subscales: res = restraint, eat = eating concerns, WC = weight concerns, SC = shape concerns

4.10 Results: Study 4

Univariate statistics

Table 4.3 describes the participant characteristics from study 4 and confirms that accurate estimators were within ~0.25 BMI units of their actual BMI, on average, as compared to over-estimators who over-estimated by ~4 BMI units. With respect to the World Health Organization's weight classification scheme (WHO, 2003), the numbers of participants who fell into the under-weight, normal, over-weight and obese categories for the accurate and over-estimating groups, respectively, were: 0, 11, 0, 1 and 1, 9, 1, 1. Cronbach's alpha for the psychometric tasks BDI, BSQ and EDE-Q in the two groups were 0.90, 0.93 and 0.94, respectively. The mean BSQ scores shown in **Table 4.3** are both consistent with mild concern with body shape (Evans & Dolan, 1993). The mean BDI scores for the accurate and over-estimating groups are consistent with the minimal and mild ranges respectively. The EDE-Q subscales in both groups all fall within 1SD of the normative means for women within this age group (Mond et al., 2006).

Where were participants fixating?

The main question we wanted to address was whether participants were fixating primarily within the midline of the stimuli or along the body edges, during each of the four conditions: i.e. masking task with: large bubbles; large bubbles open; small bubbles and small bubbles open. Therefore, our analyses focus on within task comparisons rather than between task comparisons. After blinks and saccades were removed from the eye movement time series, the only additional data filtering we applied was to remove the first 300msec post stimulus onset, as otherwise this would include the initial fixation which was determined by the fixation cross and not by the observer. In order to examine the spatial distributions of fixations we constructed a sampling grid of square cells (20 × 20 pixels each) and applied it to the fixation data that were recorded within the central 600(w) × 1020(h) pixels of the stimulus array. This cell size (20 × 20 pixels) represents a compromise between capturing as many fixation samples per cell as possible to optimize statistical power (which ideally requires large cells) versus retaining good anatomical resolution (which ideally requires small cells) (cf. George et al., 2011). Having binned the fixation data in this way, we calculated the percentage of the total fixation samples in each bin, separately for each task and participant. These fixation density data were then converted to z-scores which are presented as heat maps in **Figure 4.6.**

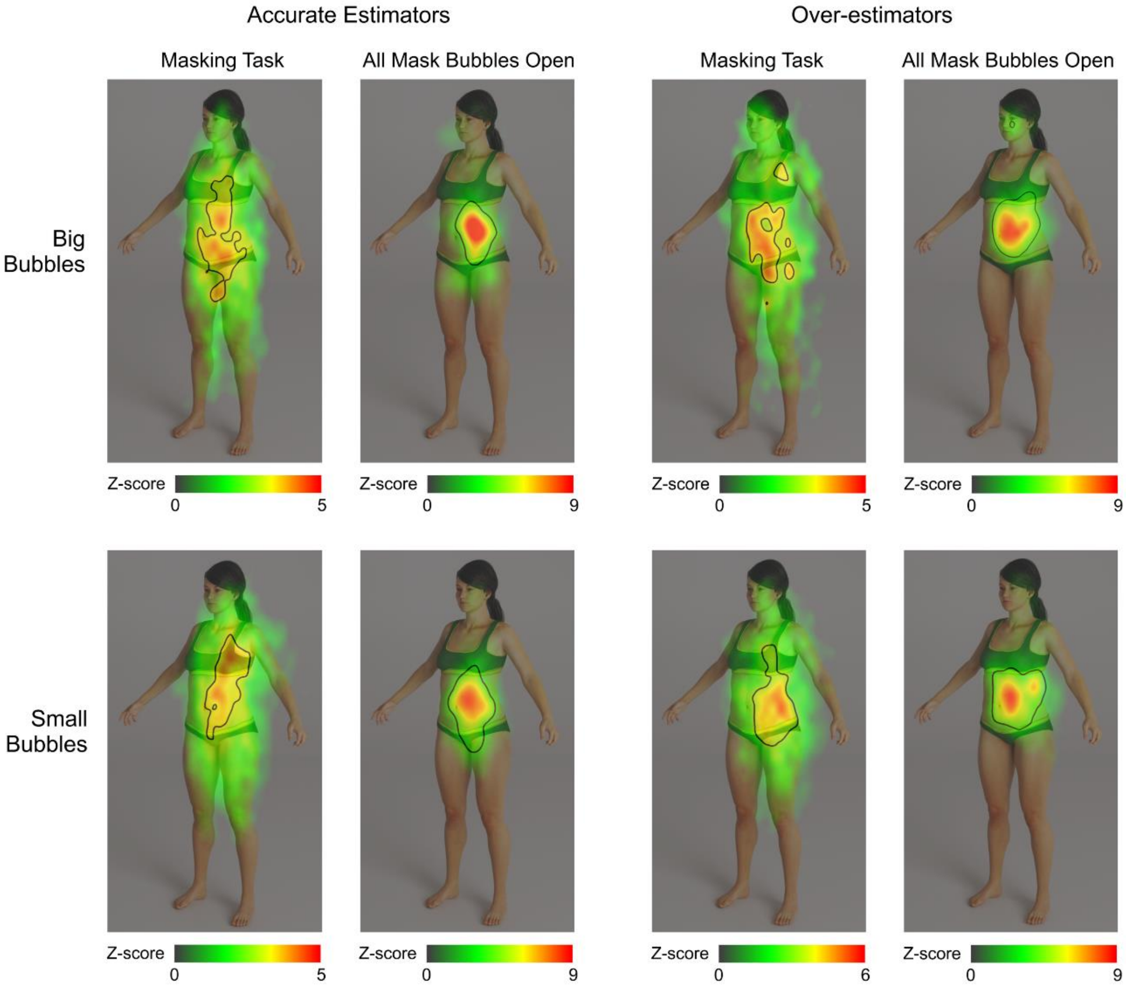


Figure 4.6. *Shows heat maps for accurate and over-estimators performance across the four eye-tracking conditions, black contours show 3SD.*

Figure 4.6 shows clearly that, irrespective of whether they viewed stimuli through small or large bubble masks, or whether they were accurate body size estimators or over-estimators, participants always showed a spatially more distributed gaze pattern during the bubble masking task as compared to viewing the stimuli when all bubbles were open. The critical question for the current study, however, is whether the gaze patterns for the bubbles task remain centred on the midline, or whether they break apart into two distributions: one centred on the left torso edge and the other on the right. Inspection of the black contours in **Figure 4.6**, which represent the three standard deviation limits in each heat map, would suggest that participants' fixations remained densest in the midline irrespective of task type or group assignment. To quantify this, we split each fixation density map into three columns of equal width, corresponding to the large bubble diameters at 0.56 deg. We then calculated the total percentage of the fixation samples in each column, separately for each participant and for each task, and used PROC MIXED in SAS v9.4 (SAS Institute, North Carolina, USA) to test for differences between the average fixation density in each column. **Table 4.4** overleaf shows the outcome including the post-hoc comparisons, controlled for multiple comparisons, between the left and middle columns and the right and middle columns of fixations. There is no case in **Table 4.4** where both left and right columns of fixation data are significantly larger than the middle column. Therefore, we found no compelling evidence that participants' fixation patterns divided into separate distributions coincident with the edge regions diagnostic of body size. However, for accurate observers during the masking task, there was evidence that their gaze patterns shifted to the left, particularly in the chest region.

Table 4.4 Comparison of fixation density in each of the three columns

Group	Bubble Size	Task	Left column (%)		Middle column (%)		Right column (%)		Left v Middle	Right v Middle
			M	*SE*	*M*	*SE*	*M*	*SE*	*p*	*p*
Accurate	Big	Mask	32.41	4.66	56.98	3.74	10.60	2.26	<.001	<.001
		No mask	20.56	5.99	75.21	6.18	5.63	3.20	<.001	<.001
	Small	Mask	41.17	5.19	50.75	3.58	8.82	2.39	.08	<.001
		No mask	17.89	4.74	77.45	4.66	5.08	2.14	<.001	<.001
Over-estimate	Big	Mask	35.09	5.26	52.80	3.44	12.11	3.48	<.001	.003
		No mask	25.53	7.57	70.98	6.99	4.19	2.53	<.001	<.001
	Small	Mask	39.64	4.86	50.82	3.19	9.55	3.29	.05	<.001
		No mask	31.34	9.76	63.18	8.71	6.58	2.92	<.001	<.001

Direct comparison between eye fixations and psychophysical performance

Clearly, direct comparisons between Studies 2 and 4 and between Studies 3 and 4 were not feasible because the outcome measures, tasks, and participant groups were all different. Moreover, the spatial sampling of data in the three studies was not directly comparable. Nevertheless, we attempted to make approximate comparisons as follows. First, we resampled the eye movement data for each participant to match that for the bubble masking tasks. To do this, we used 20 × 20 pixel sample bins placed at the centres of the small and, separately, the large bubble masks. This procedure spatially co-registered the eye-movement data precisely with the large and small bubble mask psychophysical data. Then, we converted both the behavioural psychophysical data and the eye movement data to z-scores, and re-ran the GLMMs, separately for the psychophysics and eye movement data. This allowed us to compute marginal means (i.e. LSmeans in SAS) with their accompanying 95% confidence intervals for the data at each sample point, and these are plotted in **Figure 4.7.** In each case, the solid lines represent the eye-movement data, and the dashed lines the psychophysical data. All error bars represent 95% confidence intervals in units of z-scores. The locations of the horizontal slices through the combined datasets are indicated by letter groups: *A*, *B* & *C* and *D*, *E* & *F*, for the big and small bubble mask datasets, respectively. Finally, there is a small horizontal offset in the x-axes for the eye-movement and psychophysical data, so that error bars do not overlap. **Figure 4.7** confirms that eye fixations remained densest in the mid-line of the body, while the regions diagnostic of body size were concentrated on the edges.

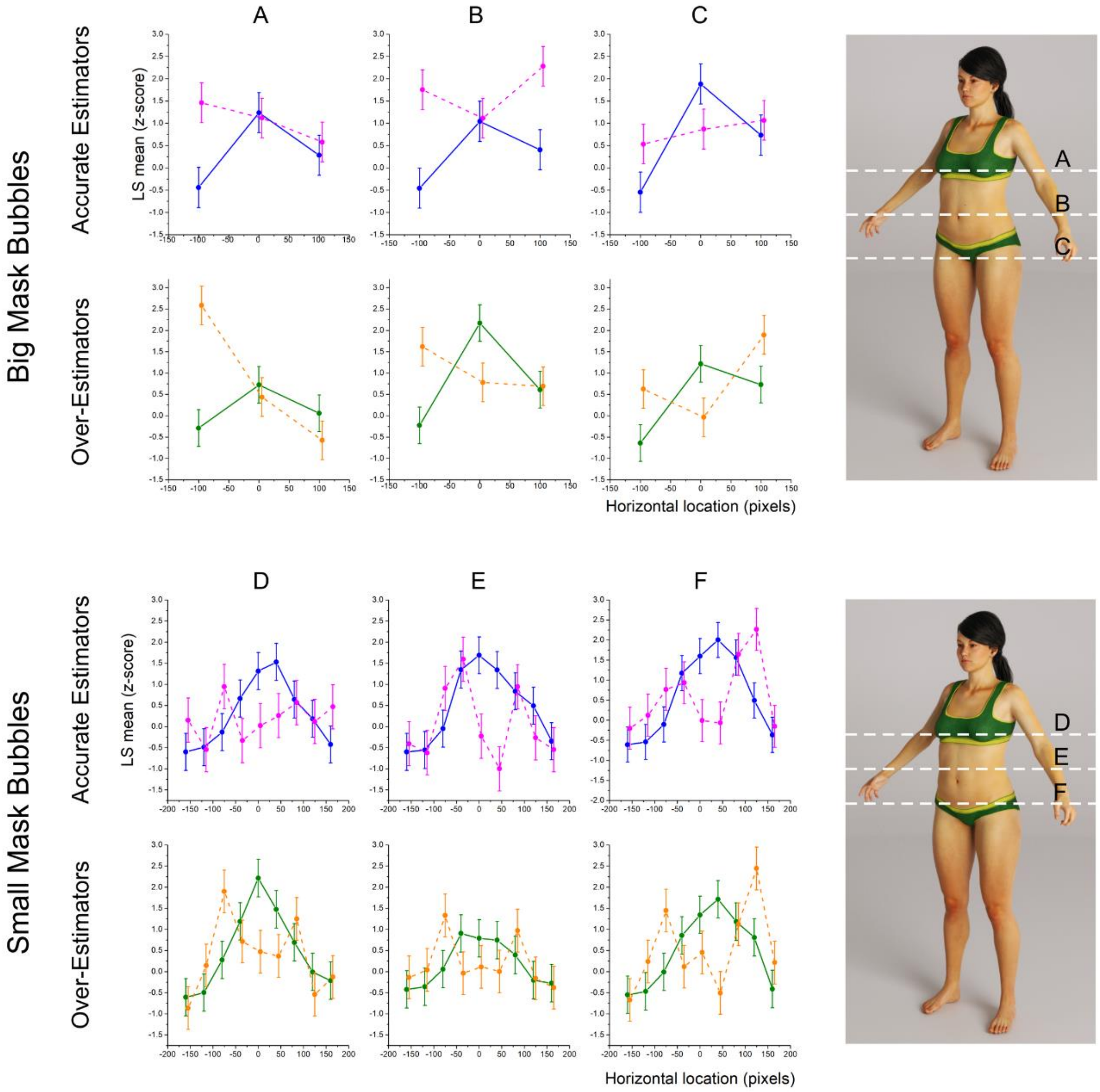


Figure 4.7 *Shows the marginal means (bars represent and 95% C.I.s) across the slices in accurate and over-estimators, for both big and small bubbles tasks. Solid blue lines represent the eye-movement data and pink dashed lines the psychophysical data for accurate estimators. Solid green lines represent the eye-movement data and dashed orange lines the psychophysical data for over-estimators. See text for further details.*

4.11 Discussion

In study 2, the results of the modified bubbles technique (using the larger bubbles) suggest that the key areas of the image for accurate self-assessment of body size are on the edge of the torso at waist height on either side of the body. Both the left and right edges of torso are of equal importance in making the judgement. Over-estimating observers favour the right side of the image relative to the left side, as illustrated by the comparison of accurate and over-estimators in **Figure 4.1**. In study 3, the results of the bubbles technique (using smaller bubbles) suggests that they key areas are located along the outline of the torso on either side of the body and at the thigh gap. Once again, both sides of the body have equal importance in accurate judgements, but there is a bias towards one side of the body in over-estimators as illustrated by the comparison of accurate and over-estimators in **Figure 4.4**. It seems that an equal division of visual attention to both side of the torso outline may be key to accurate judgements.

A potential concern is that the use of the bubble masks significantly changes the looking strategy used to assess the stimuli (Gosselin & Schyns, 2004; Murray & Gold, 2004). However, in face experiments, the diagnostic area of the face identified by the bubbles techniques for a particular task are consistent with those identified using other methods, such as comparing the performance with isolated parts of the face (Bassili, 1979; Calder, Young, Keane, & Dean, 2000), using reverse correlation (Jack, Caldara, & Schyns, 2012; Yu et al., 2012) and eye-tracking (Blais, et al., 2017). In study 4, the addition of eye-tracking to the bubbles paradigm shows that although the key regions of the torso for accurate judgements are on its edge, the visual fixations are clearly in the centre of the torso (**Figure 4.6**). This pattern of fixations is very similar to that reported by previous studies which have not used a masking paradigm, but have instead allowed a free, unoccluded view of the stimuli (Cornelissen et al., 2016b; George et al., 2011), This suggests that the use of the bubbles technique is not qualitatively altering the fixation pattern that our observers are using to estimate body size (Gosselin & Schyns et al., 2004). However, although the fixations fall within the centre of the torso, the key regions of the torso for accurate judgements are clearly on its edge.

Also consistent with previous studies (Cornelissen et al., 2016b; George et al., 2011), we found that the pattern of fixations is more diffused in inaccurate observers, spreading across the torso onto its edges (**Figure 4.6**). We found this pattern of distribution in both the trial conditions and the open mask condition (when all the Gaussian windows are simultaneously visible) for each bubble size, although the fixation distribution is spread more widely across the torso in the trial conditions. This latter difference maybe because the changing distribution of the bubbles on each trial in this paradigm limits the opportunities to fixate on the centre of the torso. The eye-movement results suggest a clear dissociation between fixation location and the location of the regions of the body stimuli that are diagnostic for self-estimates of body size.

At first sight, this dissociation might seem counter-intuitive. The physical constraints of the retina mean that detailed spatial information can only be sampled from a small central area of around 2°, corresponding to the fovea (Levi, Klein, & Aitsebaomo, 1985). As a result, information in detail and colour can only be collected in small snapshots corresponding to the observer's individual fixations (Miller & Bockisch, 1997). Thus, the failure to fixate the key regions of the body (as identified by the bubbles paradigm) so that the corresponding part of the image formed on the retina falls on the fovea is unexpected. Such a strategy should allow detailed analysis of the shape of these regions. Moreover, in a previous study in which participants are explicitly asked to judge torso shape, eye-tracking shows that fixations are initially made on one edge of the torso and then the participants' gaze moves across the torso to fixate the other edge (Cornelissen et al., 2009). They do not make a simple central fixation as is seen here.

It is possible that the fixation on the centre of the torso may be serving as a convenient way to locate an image of the torso's left and right edges on the parafoveal region (the region of the retina surrounding the fovea). The parafoveal region supports a less detailed, lower resolution sampling than the fovea, but which is still sufficient to support the detection of the edges of the torso. This perception may be enhanced by the phenomenon of hyperacuity. In this perceptual process, the cortex extrapolates detail from the limited sampling of the parafoveal cone array and so is capable of finer discrimination than the retinal structure would suggest (Gegenfurtner, 2016; Motter & Belky, 1998; Ruy et al., 2013). So even though the centre of the torso is being fixated, information about the relative position of both torso edges can be derived from the periphery of the visual field and an estimate of the body width can be made. After all, just because the observer is fixating in the centre of the torso this does not mean that their *visual attention* is focussed at the same position. Numerous studies have suggested that it is possible to direct attention at different parts of the visual field while at the same time fixating a separate part of the image (Evans et al., 2011; Motter & Belky, 1998), although it is unclear whether this allocation of attention across different parts of the visual field is achieved simultaneously or in rapid succession (Evans et al., 2011; Hüttermann et al., 2013). This should be further investigated in future work.

Therefore, if one accepts that the width of the torso is a good cue to overall body mass, then the most efficient way of sampling the visual information that will allow you to make that judgement may not be to fixate one edge of the torso and then move the eyes to fixate on the other edge of the torso. Instead, it may be quicker and simpler to foveate within the centre of the torso while directing your attention to the parafoveal regions of the retina corresponding to the edges of the torso. The previously reported difference in the pattern of eye-movements when estimating body size as opposed to judging body shape maybe because although the parafovea can support enough spatial resolution to judge the relative position of the left and right torso edges (and so judge width), it may lack sufficient resolution to detect the subtler changes in the outline necessary to judge differences in torso shape (Cornelissen et al., 2009).

This dissociation between the fixation pattern and the visual cues used in the self-estimates of body size illustrates the danger of making assumptions based on eye-tracking data. Just because someone appears to look at a certain party of the body, it does not mean they are necessarily directing their visual attention to the same place. The assumption that these two visual activities are the same can lead to misinterpretation of the data and mean that wrong conclusions are drawn on which body features are key to body size judgements. In future, it is important that eye-movement studies are paired with other techniques to localise which body features are used in a judgement, to either corroborate or clarify the results of the eye-tracking and avoid the wrong conclusions being made.

The results of these three studies provide an important clarification of exactly how people judge body size and the relative importance of the available cues. This represents vital information for guiding therapeutic strategies designed to improve the accuracy of body size judgements in those who mis-estimate body size. This is important for people who over-estimate body size (such as women with anorexia nervosa), and for people who under-estimate body size (such as people suffering from obesity), and whose misperception can lead to negative health consequences (e.g. Cornelissen et al., 2016a; Fairburn et al., 2003; Junne et al., 2018; Pike, 1998; Robinson & Kirkham, 2013). Given the dissociation between eye fixation and diagnostic regions we have found in this study of nonclinical women, it is clearly important to make the same measurements in women who have eating disorders. Based on an extensive review of the literature on visual processing in anorexia nervosa, Madsen, Bohon, and Feusner (2013) conclude that women with anorexia nervosa struggle to process global features and tend to over-value local detail. Therefore, one possible outcome of applying the bubbles technique to a body size self-estimation task in anorexia nervosa might be to reveal a very non-specific, or diffuse pattern of diagnostic regions. On each trial, it is possible that participants might lock onto one or a very few bubbles to process only those local details. However, the particular bubble locations that they choose to focus on may be quite different from one trial to the next. When averaged over multiple trials, this could lead to widely dispersed and diffuse diagnostic regions. An alternative possibility might be that, in the face of such over-attention, women with anorexia nervosa may cling to a single well focused diagnostic region, say along just one body edge.If either ofthese outcomes were true, suchfindingsmight suggest new intervention strategies to retrain how sufferers attend to images of their body, thereby helping to prevent body size overestimation. We know that such an outcome could be useful, because recent perceptual training studies have shown clinically meaningful reductions in psychological concerns about body size, shape, and eating that last for up to a month post-intervention (Szostak, 2018; Gledhill et al., 2016).

In conclusion, the bubbles results suggest that a key visual cue used to estimate body mass is the width of the torso, as the important elements of the image are located along both sides of the torso outline. Previous studies have found that the width of the torso increases with increasing BMI and so this would be a reliable cue to BMI status (e.g. Cornelissen et al., 2009; Tovée & Cornelissen, 2001; Tovée et al., 1999). In the small bubble condition, there is an additional important area of the image located at the position corresponding to the gap between the upper thighs. The diameter of the thighs is correlated with overall BMI (Ryan & Nikas, 1998) and so the “thigh gap” is a potential cue to overall adiposity, particularly for lower BMI bodies. The addition of eye-tracking to the paradigm suggests that observers use an efficient fixation strategy, fixating centrally within the torso outline to estimate its width and thereby the BMI of the body.

Chapter 5: Comparison of size estimation in 2D and 3D virtual reality, studies 5 and 6

In Chapter 1 we briefly described research by Preston and Ehrsson (2014) which suggested that adequate measurement of body image may require presentation of ecologically valid stimuli in first-person perspective, thereby permitting unambiguous body ownership. To that end, in this chapter we describe studies which use bespoke avatars of participants to test these ideas. We first present details of avatar creation and the validation of these models. This is followed by an investigation of how well participants can detect the presence of their own avatar in a scene amongst other avatars, where all information about facial identity is masked. This is important because, ultimately, we want participants to make judgements about their bodies, uncontaminated by information about their faces. Therefore, we need to know whether participants are able to identify themselves based purely on body shape alone. Finally, we compare the accuracy and precision of participants' judgements about their body size, as indexed by BMI, when performing a method of adjustment task (MoA): (i) in 2D on a standard flat panel monitor with the standard stimuli used in previous chapters; (ii) in 3D in virtual reality with a standard 3D model, and (iii) in 3D in virtual reality with a personalised 3D avatar.

5.1 Introduction

Body ownership and first-person perspective

Petkova and Ehrsson (2008) demonstrated that viewing a mannequin from a first-person perspective and experiencing synchronous touch induces feelings of ownership of the mannequin's body. Simply put, body ownership here refers to the idea that the body being viewed in the experimental setup is experienced as belonging to oneself, the same way we experience our bodies as belonging uniquely to ourselves when we look in the mirror or down towards our feet.

Using the video distortion technique to manipulate the size of a mannequin's body, Preston and Ehrsson (2014) demonstrated associations between perceptual and affective body representations. Specifically, Preston and Ehrsson (2014) found that inducing illusory ownership over a mannequin body which was 15% thinner (as manipulated using VDT) than a participant's own body lead participants to judge their own body as slimmer. Moreover, following the experience of the illusion, participants also expressed higher body satisfaction with their own body compared to ratings obtained before the illusion was induced. However, in this study, owning a larger body did not lead to a decrease in body satisfaction. One possible reason for this is that the video distortion technique does not allow realistic manipulations of body size, as discussed in Chapter 1 (pp. 31-34). For example, the stomach of Preston and Ehrsson's (2014) mannequin remained flat, regardless of whether it was supposed to represent a larger or smaller size.

In a more recent study, Preston and Ehrsson (2016) overcame this limitation by using pre-recorded videos of real slim and obese bodies and found that inducing ownership over an obese stranger's body did indeed reduce body satisfaction in otherwise normal-sized participants. However, owning a realistic slim body did not change satisfaction in the way that a slim mannequin's body did in their earlier study (Preston & Ehrsson, 2014). The authors concluded that this was a result of the sample being normal-sized (mean BMI of 22.2) and close to that of the slim stimuli (BMI of 20.4). By comparison, in Preston and Ehrsson (2014), the sample's BMI was not only lower (mean BMI of 20.7) but also the presented stimuli were deliberately made to look smaller than the participant.

A further investigation of body satisfaction by Preston and Ehrsson (2018) attempted to extend their findings to implicit body satisfaction. Assessing attitudes using explicit measures such as questionnaires may not always be reliable as they are subject to response and motivational biases (Hofmann, Gawronski, Gschwender, Le, & Schmitt, 2005; Nevid & McClelland, 2010). However, tasks that measure implicit attitudes are designed to gauge automatic and unconscious feelings, which are believed to play an important role in eating disorder pathology and which may be better allied to a participant's psychological state (Robinson, Safer, Austin, & Etkin, 2015). Accordingly, Preston and Ehrsson, (2018) measured explicit satisfaction with the Body Image States Scale (BISS; Cash, Fleming, Alindogan, Steadman, & Whitehead, 2002) and implicit body satisfaction with an adapted form of the implicit association task (Greenwald, McGhee, & Schwartz, 1998) in which associations between the self and statements about attractiveness were identified. For example, in the implicit task, participants categorised words (e.g. 'ugly', 'gorgeous') as either attractive or unattractive, and decided whether they referred to 'self' or 'other', so that there were 4 possible response options: self/attractive, self/unattractive, other/attractive, other/unattractive.

Preston and Ehrsson (2018) found that scores on the implicit task were not influenced by the size of the body used in the illusion, i.e. the implicit association between self and attractive words increased irrespective of whether the body owned was slim or obese. In terms of explicit body satisfaction Preston and Ehrsson (2018) found that illusory ownership of an obese body (using stimuli of real bodies again) led to reductions in explicit body satisfaction, replicating their earlier studies. Notably, women who scored highly on the EDE-Q reported greater implicit and explicit body dissatisfaction following illusory ownership of an obese body, compared to low-scorers. This suggests that for women with less stable affective representations of their body, perceived weight gain can strongly impact body satisfaction.

Across several studies, it is clear that Preston and Ehrsson have shown that illusory ownership can influence how one feels about one's body. In our opinion, this raises a key question. If we want participants to estimate their own body size accurately, should the task be presented in first person or third person point of view? Should the observer have ownership of the body they are viewing? Intuitively, it seems that the most ecologically valid situation for such measurements would be to have a participant looking in the mirror, dynamically manipulating the size of the image in the mirror to match the body size the participant feels themselves to have. However, to achieve this with stimulus imagery that represents BMI-dependent body shape changes correctly would be difficult without virtual reality. Other options, such as animatronic suits or using adaptive optics with a real mirror, would be extremely expensive and technologically demanding. In addition, using an animatronic suit would not allow participants to express body size that is smaller than their own. As such, we have chosen to use virtual reality as an accessible and affordable option to test these ideas.

What is virtual reality?

Recent technological advances have allowed virtual reality (VR) to become an affordable and therefore widely available research instrument. The essence of VR is the immersive and interactive relationship between the user and the virtual environment. Users interact with the virtual environment with specialised controllers that track hand position and orientation, and they wear head-mounted displays (HMD). The headset also tracks head position and rotation (6 degrees of freedom: roll, pitch and yaw). The HMD has a separate display for each eye thereby allowing recreation of stereoscopic depth in the scene. In our studies we use the Oculus Rift, which uses the interpupillary distance (IPD, 58 - 72mm) and the adjustable eye relief, physically set on the HMD, to calculate the correct projection for the display images. Combined with the head tracking information, the environment can be drawn at true 1:1 scale. In other words, the scale of the scene presented through the VR headset closely matches the scale of the real world. The Fresnel lenses of the HMD adjust the eye accommodation to a more comfortable distance (near infinite focal distance); these lenses introduce distortion, which is compensated for by distorting the rendered image in the opposite direction. Virtual reality provides full freedom to interact with and observe the environment from within, as opposed to observing from an external point of view as one would with a monitor or projection. These characteristics are used to stimulate the user’s senses in order to create a sense of *immersion* and *presence*.

Presence is a state of consciousness, the psychological, behavioural and subjective sense of being in the virtual environment, a sense of “being there” (Gorini, Capideville, De Leo, Mantovani, & Riva, 2011; Riva & Waterworth, 2003; Riva, 1998). Presence is the central goal of virtual reality, perhaps a defining feature (Steur 1992, cited by Slater & Wilbur, 1997). As a subjective experience, presence can typically be measured by self-report but also can be reflected in physiological markers, such as increased heart rate (Meehan et al., 2002).

Achieving presence is difficult, it is dependent on multiple factors, many of which are dependent on the technology used. For example, low latency and high image refresh rates are essential to avoid virtual reality sickness, which is similar to motion sickness, and can prevent users from experiencing presence. Sensory conflict theory can help explain the sickness; it posits that motion sickness occurs when a user's perception of self-motion is based on incongruent sensory inputs from the visual system, vestibular system, and non-vestibular proprioceptors, particularly when these inputs are at odds with the user's expectation based on prior experience (Reason & Brand, 1975). In VR a number of factors are associated with sickness, such as refresh rate and image latency. Refresh rate is the number of times in a second the display hardware updates its buffer. This is important because it is related to the perception of flicker. Slow refresh rates increase the sense of flicker which, in turn, induces eye-fatigue and has been shown to cause VR sickness (Almeida, Rebelo, Noriega, & Vilar, 2017). Image latency is the time between the movement (of the head and/or controllers) being detected by the HMD and/or controllers and the display updating accordingly. This delay needs to be as short as possible, otherwise the disparity between visual retinal slip and/or optic flow and cues from the vestibular system can also contribute to sickness (Kolasinski, 1995).

Importance of ecologically valid stimuli in VR

As discussed earlier, in Chapter 1, recent published research involving perceptual body image and the estimation of body size has used CGI models (Alexi, Clearly, Dommissee, & Palermo, 2018; Cornelissen et al., 2017, 2016; Piryankova et al., 2014b), as have we in studies 1-4. This strategy, while an improvement on the video distortion technique and figure/silhouette drawing scales, remains imperfect. The most obvious limitation is the choice of a standard model for the stimulus, where all participants make judgements about themselves in relation to changes in the same stimulus model. This ignores individual variation in the underlying body shape of different observers (as illustrated in **Figure 5.1** overleaf). A standard model may be a good fit for some participants/observers, but not all. This anthropomorphic variation represents a participant-dependent source of variability that needs to be evaluated, and potentially controlled for. In addition, we assume that asking participants to compare themselves against a standard model requires an element of cognitive mapping between themselves and another individual (Stewart et al., 2012). Again, since this represents a cognitive load, there is likely to be additional individual variation that may need to be controlled.

Figure 5.1 *Illustration of real body shape variation, each row presents individuals of approximately the same BMI (Tovée et al., 1999).*

5.2 Avatar creation and validation

One solution to these problems is to create personalised avatars. Therefore, in collaboration with Andrew Irvine from Virtual Research Innovations, (VRI) Ltd. we developed a software suite to create personalised avatars for use in Virtual Reality. First, we present details of how we create the bespoke avatars and how we validate them.

5.2.1 Method

The methods for participant recruitment and experimental procedures were approved by the Faculty of Health and Life Sciences Ethics Committee at Northumbria University.

Participants

Forty participants were recruited into this study. To be eligible, participants had to be female (as assigned at birth), aged 18 - 35, fluent in English, with no history of eating disorders, and with healthy vision (including those with vision corrected with contact lenses). Potential participants with a history of motion sickness were advised not to take part. Participants were recruited on a voluntary basis from the population of undergraduate and postgraduate students, the staff at Northumbria University and the general population in Newcastle upon Tyne (by word of mouth), all of whom gave their consent to take part in the study. Undergraduate students were given SONA points for their participation.

Measures

Anthropometric measures

Participants' body mass index (BMI) was calculated from their weight and height measured with a set of calibrated clinical SECA scales and a stadiometer respectively. In addition, 13 participants consented to have their waist and hip circumferences measured with a tailor tape. The waist circumference was measured at the narrowest point of the abdomen, midway between the iliac crest and the costal margin (cf. HSE, 2014). The hip circumference was measured at the widest circumference over the buttocks and below the iliac crest. Each measurement was repeated five times and the average was recorded.

Photographs and Avatar creation

Participant's bespoke avatars were created based on two photographs of the participant, taken from the front and side. Participants were required to wear underwear only; alternatively, they could wear close-fitted clothing, which was neither loose nor tight on the body so as not to distort their features. As such, some participants wore leggings or sports bras. They were asked not to wear black clothes, as this made it very difficult to see participants' body features when carrying out the 3D modelling.

The camera we used to take the photographs was a Canon 5D Mark III EOS with a Canon 24-70mm lens (focal length set to 50mm). The camera was placed 3.5 meters away from the participant, on a tripod at a fixed height of 135cm, and levelled using a built-in spirit level. The room where the photographs were taken was well-lit by fluorescent lights, and the lighting was supplemented by a Jessops 360 AFDC flash. A white sheet of fabric hung ~25cm behind the participant to ensure that all the features of their body shape were clearly visible. To ensure anonymity, but to retain information about participants' heights, a strip of grey fabric hung 20cm in front of the participant's face, in such a manner that their face was obscured, and only their chin and top of the head were visible (see **Figure 5.2**).

For the front photograph, each participant adopted a standard T-pose, with their feet straight below their hip joints, arms up at 90°, with their back straight. For the side photograph, the participant turned sideways, and their left side was photographed. They were instructed to place their right arm down alongside their body and lift their left arm out at 90 ° pointed towards the camera, so that the whole sagittal cross-section of the body was clearly visible (see **Figure 5.2** overleaf for an example).

Figure 5.2 *Shows an example of how the photos were taken, the person in the photograph has consented to these photos being used. Please note these are not photographs of an actual participant.*

Each photograph was cropped in Adobe Photoshop, saved as a J-PEG file and imported into the VR software (VRI, Ltd.), which runs on the Unreal Engine v14.8, as an object texture and applied to plane which was placed behind a 3D base female body model using an orthographic projection. This is a standard method in 3D modelling when using 2D reference images to create 3D models, in which all the projection lines are orthogonal to the projection plane. Simply put, the scene has no perspective, objects at any distance are displayed at the same scale, allowing object size and shape to be compared directly.

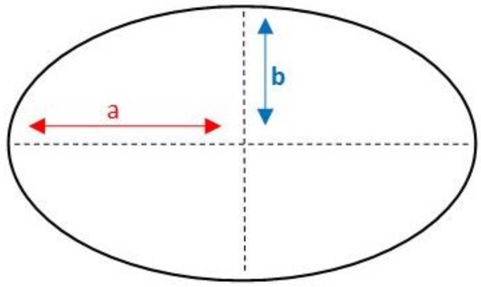
The base model was created from a reference model provided by Manuel Bastioni Laboratory (http://www.manuelbastioni.com/). Thirty-six morph targets were created for the new base model, e.g. waist size, upper thigh girth. Each morph target area could be either increased or decreased in size. The base model was then adjusted to replicate the shape and size of the participant. Firstly, the model's height was set to that of the participant, then the size of the photograph in the background was re-scaled to match the height of the base model. This was followed by adjustments of the limb length segments to match those of the participant. Then, the 36 morph controls were used to adjust the shape of the base model to the front and side view photographs of the participant, visible in the background**.** As the only focus of the study was body shape, head and facial features were not visible, they were masked with white ovoids.

Bespoke avatar validation measurements

Following avatar creation, the next step was to check how closely each avatar resembled the participant's body. The ellipse circumference formula (**Figure 5.3**) was used to calculate an estimated circumference of five body sites: bust, under-bust, waist, hips and mid-thigh of both the photograph and the avatar.

$$h = \frac{(a-b)^2}{(a+b)^2}$$

$$p \approx \pi\,(a+b)\left(1 + \frac{3h}{10 + \sqrt{4-3h}}\right)$$



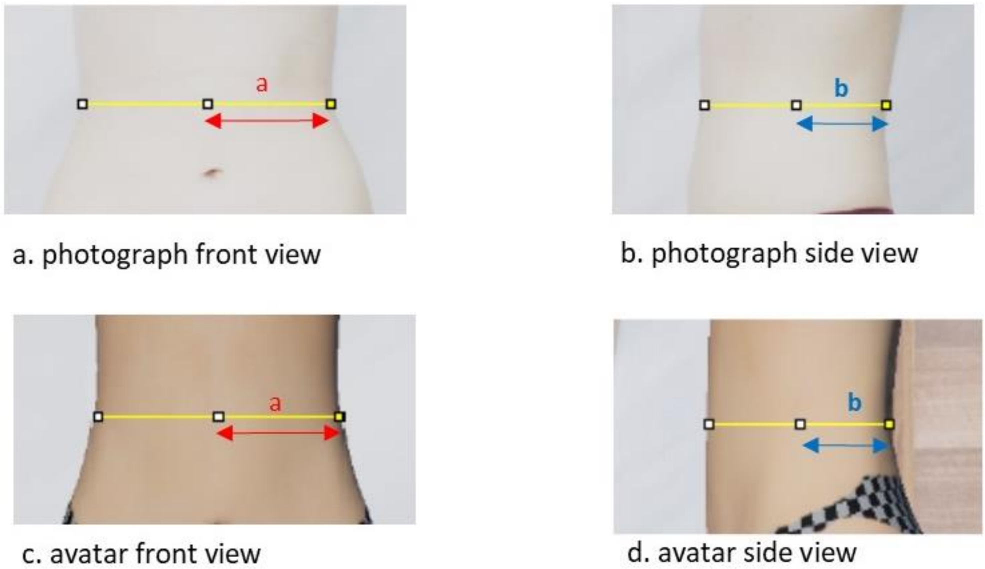


Figure 5.3 *The ellipse circumference formula, along with a schematic representation of the a and b axes; and an example of pixel measurements (yellow lines) of a participants waist, for both the photograph and avatar with schematic representations of the a and b axes.*

To measure *a* and *b* axes, each participant's model was positioned next to their photograph in the VR software (VRI, Ltd.). A screenshot was taken and saved as a .png file. Using the ImageJ (NIH) image processing program, each participant's height was measured in pixels. Since each participant's height was also measured in reality, we could use this information to calibrate the relationship between pixel distance in the images and real-world body measurement in centimetres. We then obtained 5 horizontal body measurements in both front and side view: waist, hips, bust, under-bust and midthigh using ImageJ (NIH), illustrated by yellow lines in **Figure 5.3.** These measurements were converted to real world distances (in cms) and substituted into the ellipse equation, presented in **Figure 5.3**. Using this technique, we calculated an estimated circumference of the five body sites for both the photograph and the avatar.

Procedure

During the visit, the participants read the Information Sheet, consented to take part, and had their height and weight measured. They were then instructed on how to adapt the standardised T-pose. They undressed behind an occluder, which was removed once participants were ready to be photographed. They adapted the T pose, and the photographs were taken from a distance of 3.5m. Lastly, for those who consented (n=13), additional tape measurements were taken. This session lasted about 30 mins per participant.

5.2.2 Results

First, in **Table 5.1** we present the mean actual waist and hip circumferences measured from 13 consenting participants, along with circumferences estimated from both their photographs as well as their avatars. We also present a comparison between the actual measurements and the photo estimates, and actual measurements and avatar estimates, expressed in both centimeters and percentage error.

Table 5.1 Means and standard deviations of waist and hips circumferences for actual measurement, an estimate based on photograph, and an estimate based on the avatar, along with comparison of actual tape measurement and the estimates in cms, and percentage error, in cms (n=13)

	Actual		Photo				Avatar			
	M	*SD*	*M*	*SD*	*Diff in cms (SD)*	*%error (SD)*	*M*	*SD*	*Diff in cms (SD)*	*%error (SD)*
Waist	74.42	6.81	72.82	7.84	1.59 (2.85)	2.17(3.69)	72.25	6.83	2.16 (2.26)	2.87 (2.92)
Hips	99.55	6.61	96.57	7.60	2.98 (2.32)	3.05 (2.39)	94.05	7.44	5.50 (2.94)	5.56 (3.01)

Note: Diff = difference

Table 5.1 shows that percentage error ranged from 2.17 - 5.56%, which is comparable to percentage error reported in Cornelissen et al. (2017) who also created bespoke avatars of their participants, albeit that their avatars were based on 3D body scans. The differences in average waist circumference across the three different measurements (actual, photo and avatar) are rather small, the differences for the hip measurements are larger. This is due to limitations in the current version of the modelling software, which is still being developed. Specifically, with the current base model and software tools, we were not fully able to recreate the gluteus maximus area of the buttocks (sagittal plane, depth) without widening the hip area of the avatar (frontal plane). We decided to compromise by ensuring that the width of the hips in the coronal plane was modelled as accurately as possible and allowed error to remain when modelling the buttock shape of the avatar. A new version of the software, created following completion of this study, allows the use of full 3D body scans (3dMD), thereby overcoming this problem. We return to this consideration in the discussion.

The circumferences of the five different body sites were calculated for every photograph and every model (n = 40) used in the studies described in this chapter. The averaged estimated circumferences (and SDs) are presented in **Table 5.2** below, along with differences in estimated circumferences between photograph and avatar expressed in centimetres and percentage error.

Table 5.2 Means and standard deviations for circumferences calculated from both photographs and avatars, and the percentage error between the two, in cms, n=40

	Photo		Avatar		Difference in cms	%error (SD)
	M	*SD*	*M*	*SD*		
Bust	85.47	7.80	86.50	6.51	-1.03	-1.28 (3.97)
Underbust	75.47	6.78	73.20	6.79	2.27	2.98 (3.35)
Waist	71.59	7.80	71.37	6.51	0.22	0.08 (3.68)
Hips	95.75	8.65	94.33	7.68	1.42	1.34 (3.29)
Midthigh	49.36	5.28	49.39	4.80	-0.03	-0.32 (5.68)

Despite our best efforts, it is clear that some residual error in model creation remains, particularly in the hip and under bust areas. Accordingly, study 5 investigated participants' ability to detect the presence of their avatar in a scene, based on body shape information alone.

5.3 Study 5 – Sensitivity to identity

Here Signal Detection Theory (SDT) (Gescheider, 1997; Green & Swets, 1966) was used to investigate participants' sensitivity to the presence of their own avatar among other avatars in the VR scene. According to SDT, when an observer performs a detection/discrimination task, it involves two factors: (i) signal strength, here whether the avatar is present or absent, and; (ii) their internal criterion, or bias (C) that an individual has (Stanislaw & Todorov, 1999). In this study, we have full control over the signal strength, as the avatar of the participant is either present or absent, as well as over the 'noise', i.e. other avatars present in the scene. Sensitivity is conceived as detecting a signal against background noise, here, being able to identify one's own avatar among other avatars. The sensitivity index, or Dprime (d'), provides the separation between the means of the signal and the noise distributions, compared against the standard deviation of the signal or noise distributions (Gescheider, 1997), see **Figure 5.4** below. Correct responses, also referred to as hits, are the proportion of ‘avatar present’ trials to which a participant responded ‘yes, my avatar is present’. The false alarm rate is calculated as the proportion of ‘avatar absent’ trials to which subjects also responded ‘yes, my avatar is present’. **Figure 5.4** illustrates the possible response categorisations. Bias (C) is a measure of response bias (i.e. the inclination of the participants to say ‘yes’ or ‘no’). A value greater than 0 indicates a conservative bias (a tendency to say ‘no’ more than ‘yes’), while a value less than 0 indicate liberal bias (a tendency to say ‘yes’ more than ‘no’). **Figure 5.5** illustrates the effects of participants shifting their criterion. Simply put, if responding with a liberal/low criterion, (e.g. responding ‘yes’ to almost everything), an observer will have a very high hit rate. However, they will also have a high number of false alarms. On the other hand, responding with conservative/higher criterion, (i.e. responding ‘no’ to almost everything), will lead to rare false alarms and the real hit rate will be low**.** The equations for calculating Dprime and bias from the hit rate and false alarm rate are given at the beginning of the Results section.

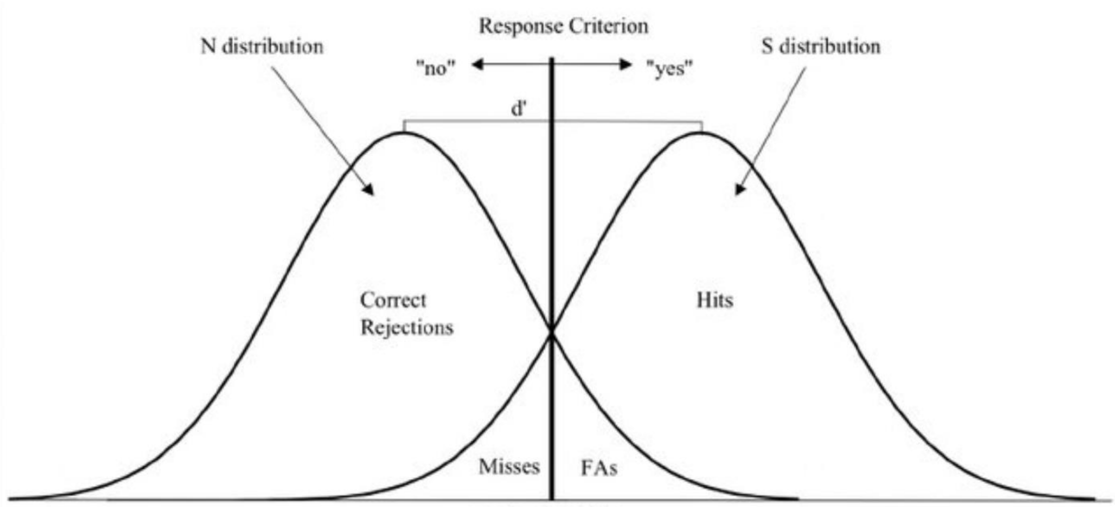


Figure 5.4 *Illustrates the response categorisation according to Signal Detection Theory (figure reproduced from Higham & Arnold, 2007, with permission).*

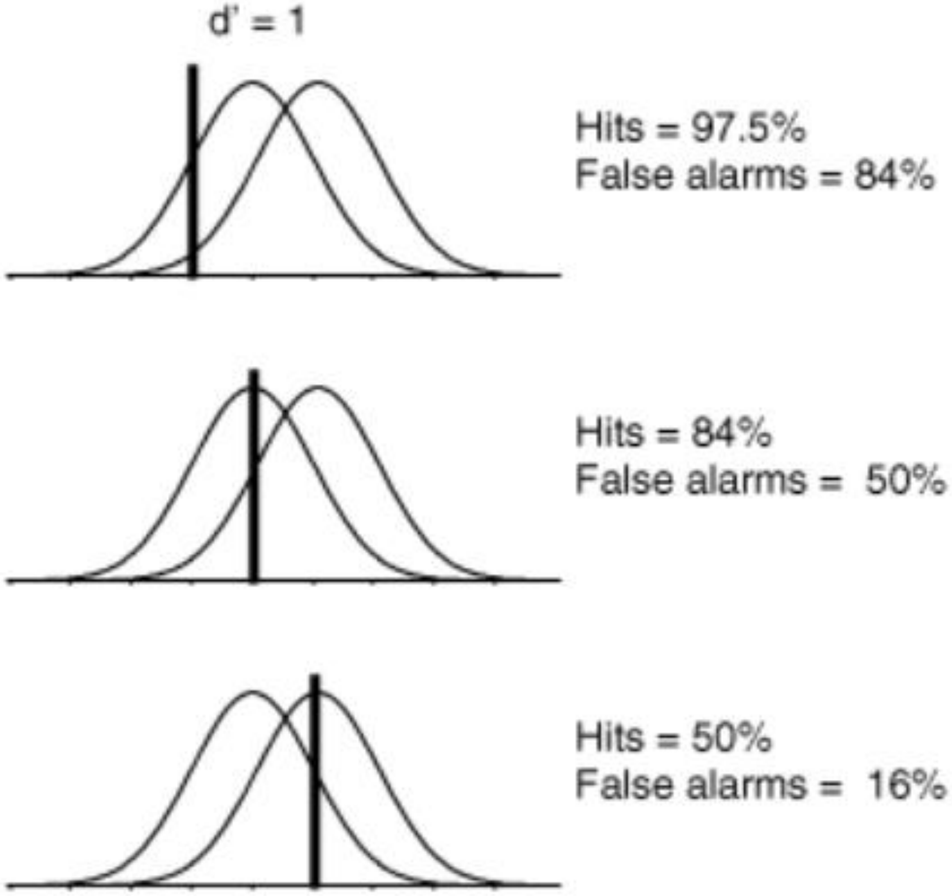


Figure 5.5 *Illustrates the effects of shifting criterion, top panel shows low criterion, bottom panel shows high criterion (Heeger, 2018).*

5.3.1 Method

The methods for participant recruitment and experimental procedures were approved by the Faculty of Health and Life Sciences Ethics Committee at Northumbria University.

Participants

Twenty-two female participants were recruited from the population of undergraduate and postgraduate students and staff at Northumbria University, as well as the general population in and around Newcastle upon Tyne (by word of mouth). Two participants did not complete the second part of the study: one experienced discomfort while wearing the Oculus Rift and withdrew, while another participant did not return for the second session. The remaining 20 participants (M *age* = 23.35, SD *age* = 5.79) fulfilled the following eligibility criteria: they were female (as assigned at birth), aged 18 - 35, fluent in English, had no history of eating disorders, and had normal or corrected to normal vision. We advised potential participants who suffer from motion sickness not to sign up to the study. Undergraduate students were given SONA credits for taking part. These participants' avatars were amongst the 40 avatars included in the validation. Additionally, 15 of these participants also took part in study 6. **Table 5.3** below shows the characteristics of the participants.

Table 5.3. Participant characteristics for VR identity tasks, n=20

			Range	
	M	*SD*	*Actual*	*Potential*
Participant characteristics				
Age (years)	23.35	5.79	18 - 35	18 - 35
BMI (kg/m^2)	21.80	3.96	15.97- 31.35	
Depression and self esteem				
RSE	20.00	5.38	8 - 28	0 - 30
BDI	11.00	40.43	0 - 40	0 - 63
Body shape and eating concerns				
BSQ	36.35	17.78	16 - 83	16 - 96
EDE-Q restraint	1.13	1.12	0 - 3.60	0 - 6
EDE-Q eating concern	0.72	0.99	0 - 4	0 - 6
EDE-Q weight concern	1.57	1.60	0 - 4.8	0 - 6
EDE-Q shape concern	2.06	1.65	0 - 5.5	0 - 6
EDE-Q global	1.37	1.25	0 - 4.48	0 - 6

Note: *BDI = Beck Depression Inventory , RSE = Rosenberg Self-Esteem Scale, EDE-Q = Eating Disorders Examination Questionnaire with subscales, BSQ = Body Shape Questionnaire*

Measures

Anthropometric measures

Each participant's body mass index (BMI) was calculated from their weight and height measured with a set of calibrated clinical SECA scales and a stadiometer respectively.

Psychometric measures

The participants completed the following questionnaires as described in Chapter 2: (i) Rosenberg Self-Esteem Scale (RSE; Rosenberg, 1965); (ii) Beck Depression Inventory (BDI; Beck et al., 1996); (iii) Body Shape Questionnaire (BSQ; Evans & Dolan, 1993); (iv) Eating Disorders Examination Questionnaire (EDE-Q; Fairburn & Beglin, 1994). Cronbach's alpha for each measure was: RSE α = .904; BSQ α = .961; EDE-Q α = .961; BDI α = .941; suggesting good internal consistency.

Stimulus preparation

Participants' bespoke avatars were created in the VR software (VRI, Ltd.) based on two photographs of the participant, as described in the Model Validation section 5.2.

Virtual Reality Yes/No identity categorisation task

For this task, testing took place in a dedicated room with three Oculus VR sensors positioned at three points (front-left, front-right and one behind the participant) triangulating the virtual space. This left a 3 x 3m space in which participants could move about freely. Once the headset was fitted, the calibration process was started. Each participant's height was entered into the control software, and the positional calibration of the Oculus Rift VR set up was completed automatically. This procedure allows the sensors to work with the headset to track and match the movement in virtual reality (positional head tracking).

Participants wore the Oculus Rift headset (1080 x 1200 pixel resolution, global refresh rate of 90Hz), and used the Oculus Touch controllers to start each task by hitting a ‘start’ box, and also to indicate their responses by ‘hitting’ virtual response boxes on each trial. The participants were informed that they would see a number of life-sized avatars, scaled 1:1 (i.e. accurately life-sized), arranged on a semi-circle, and that they needed to decide whether their own avatar was present among them. Here, a yes-no categorisation task was used. The participants were asked to respond with either “yes” (as in ‘yes, my avatar is present’) or “no” (as in ‘no, my avatar is not present’), using the Oculus Touch controllers. There was no time pressure to respond. Once a decision was made the avatars disappeared and after 2 seconds a new, randomised line up appeared.

Once the study began, participants were presented with three separate conditions: blocks of 60 trials in which 2, 4 or 6 avatars were presented. Avatars appeared in front of the participant facing towards her. The avatars were arranged, with equal spacing, on a semi-circle, with the participant at its centre (radius of 2 meters), **see Figure 5.6** overleaf for illustration. Participants were told that they could move about, turn around, and approach the avatars. Between each block, participants were asked if they needed a break, if they were feeling well and if they still could see everything clearly. When necessary the set up was re-calibrated. Participants completed 60 trials in each condition (2, 4 or 6 avatars present), where their avatar was presented in the ‘line up’ half the time and absent for the remaining half. The order of present/absent trials was randomised in real time. The other avatars in the line-up were the other participants’ avatars (all participants consented to their avatars being used for this). The models’ heads were covered with white ovoids to mask facial features, ensuring that decisions about identity had to be primarily driven by avatar body shape.

Figure 5.6 *An illustration of how the stimuli were arranged in the 4 avatar condition. Note, that all models shown are the base model and that the viewing distance at which they are presented is for illustrative purposes only.*

Procedure

The procedure was split into two visits. During their first visit, participants read the Information Sheet, consented to take part and they had their height and weight measured. They were then instructed on how to adopt the standardised T-pose, were shown where to change clothes/undress, and were then photographed as described above. This session took about 30 mins per participant. The bespoke avatar was made for each participant as soon as possible, typically within two days. Session two typically took place after one week. In the second session, the participants were instructed how to wear the Oculus headset, adjust the focus to ensure that the VR scene was clearly visible, and how to use the Touch Controllers. Once familiarised with the set-up, the Oculus Rift was calibrated, i.e. sensor position was adjusted, participant's height was entered and sensors scanned the position of the headset. The participants then performed the three conditions of the Virtual Reality Yes/No identity categorisation task as described above.

5.3.2 Results

Absolute z scores: unusualness of height and BMI

We felt it was likely that the extent to which an individual's height and/or BMI departed from the averge for the set of avatars used in the exeriment, might provide a salient clue to their identity. To quantify this potential effect, we wanted a measure of surprise which could be included as a covariate in the statistical anayses. To do this, we converted participants' heights and BMIs to z-scores, and took the absolute value of these scores as our metric. Zero represents a height/BMI consistent with the average for the avatar group. Larger values represent heights/BMIs that are either substantially smaller or larger than the average.

Response sensitivity (Dprime) and bias (C)

First the hit rate (HR) and false alarm rate (FR) were calculated, and transformed into their respective z-scores. These values were then used to calulate dprime and bias (C) as follows:

Dprime = z_HR - z_FA

C = - (z_HR + z_FA) / 2)

The results per condition are presented in **Table 5.4**.

Table 5.4. Correct responses (proportion), Dprime, and response bias (C) across the three conditions, n=20

	Condition					
	2-Avatar		4-Avatar		6-Avatar	
	M	*SD*	*M*	*SD*	*M*	*SD*
Correct response (proportion)	0.73	0.20	0.74	0.22	0.73	0.23
D-prime	2.16	1.19	2.04	1.50	2.11	1.37
Bias, C	0.24	0.24	0.04	0.24	-.047	0.27

We used PROC UNIVARIATE to calculate tests of location (i.e. $\mu = 0.5$) for the probability of a correct response. For the 2-avatar: $t(19) = 5.22$, $p < .0001$, 4-avatar $t(19) = 4.84$, $p < .0001$, and 6-avatar $t(19) = 4.35$, $p < .0003$ conditions, these probabilities were significantly above chance responding.

In **Table 5.4** we can see that as more avatars are present in the lineup, participants' criterion (bias, C) becomes more negative. A relaxed/lower criterion, where participants are more likely to say 'yes' means a combined increase in hit rates and false alarm rate, the midpoint between the noise and signal distribution shifts to the right, and C becomes negative (see **Figure 5.5** above). If participants use a stricter criterion and only say 'yes' when they are much more certain the midpoint between the noise and signal distribution shifts to the left and C becomes positive. Here we can see as there are more people added to the lineup, the criterion (C) lowers and becomes negative, which means that participants were more likely to say 'yes'. Importantly however, despite this criterion shift, absolute sensitivity (Dprime) has not changed and remains high.

Correlations of Dprime, Bias (C), psychological variables, height and BMI unusualness

Here we wanted to investigate the extent to which (i) our experimental conditions and (ii) height/BMI unusualness influenced Dprime and bias (C). In addition, since prior research on body size estimation shows that perceptual body image judgements are influenced by the psychological state of participants (Cornelissen et al., 2016a, 2016b), we looked for influences of RSE, BDI, EDE-Q and BSQ on Dprime and C. **Table 5.5**, shows Pearson correlations between all these variables. As none of the psychological scores were significantly correlated with either Dprime or bias, they were not considered further in the multivariate analysis.

Table 5.5. Pearson's correlations between psychological variables, Dprime and C, n=40

		RSE	BDI	EDE-Q	BSQ	Height unusualness	BMI unusualness
2-avatar							
	C	-.10	.05	.02	-.04	-.18	-.29
	Dprime	.26	-.09	-.16	-.14	-.61**	-.34
4-avatar							
	C	-.04	-.03	-.14	-.23	-.21	-.35
	Dprime	.25	-.22	-.31	-.25	.57**	.47*
6-avatar							
	C	.10	-.22	-.13	-.21	-.12	-.40
	Dprime	.22	-.07	-.15	-.04	.42	.59**

Note: *p < .05, **p < .01

Multivariate statistics

We used Proc MIXED in SAS v9.4 (SAS Institute, North Carolina, USA) to build separate linear mixed effect models for sensitivity (Dprime) and bias (C). The fixed effects in each model included: (i) condition (2-avatar, 4-avatar, 6-avatar), (ii) unusualness of height, and (iii) unusualness of BMI. In addition, we permitted individual variation at the intercept level for each observer, by including a random effect with an unstructured variance-covariance matrix in each model.

Sensitivity

The Type 3 tests of fixed effects for sensitivity showed a statistically significant fixed effect of height unusualness $F(1,15.4) = 7.52$, $p = .014$, but no significant fixed effect of the unusualness of BMI $F(1,15.4) = 3.20$, $p = .093$, and no significant effect of condition $F(2,31.8) = .99$, $p = .382$. This suggests that sensitivity to own avatar may be influenced by the participant's height, i.e. those participants of unusual height may have used this information to their advantage when performing the task.

Post-hoc pairwise comparisons of LSmeans controlled for multiple comparisons showed no statistically significant differences in sensitivity (Dprime) between the 2- and 4-avatar conditions $t(31.9) = 0.43$, $p = 0.67$; the 2- and 6-avatar conditions $t(31.7) = 1.38$, $p = 0.17$; nor the 4- and 6-avatar conditions $t(31.7) = 0.97$, $p = 0.33$.

Figure 5.7 shows that the more an individual participant's height deviated from the mean for the group, so did the Dprime scores increase. In other words, unusually tall or short participants were more sensitive to their avatar's presence in the line-up. While a similar effect is observed for BMI, it did not reach significance.

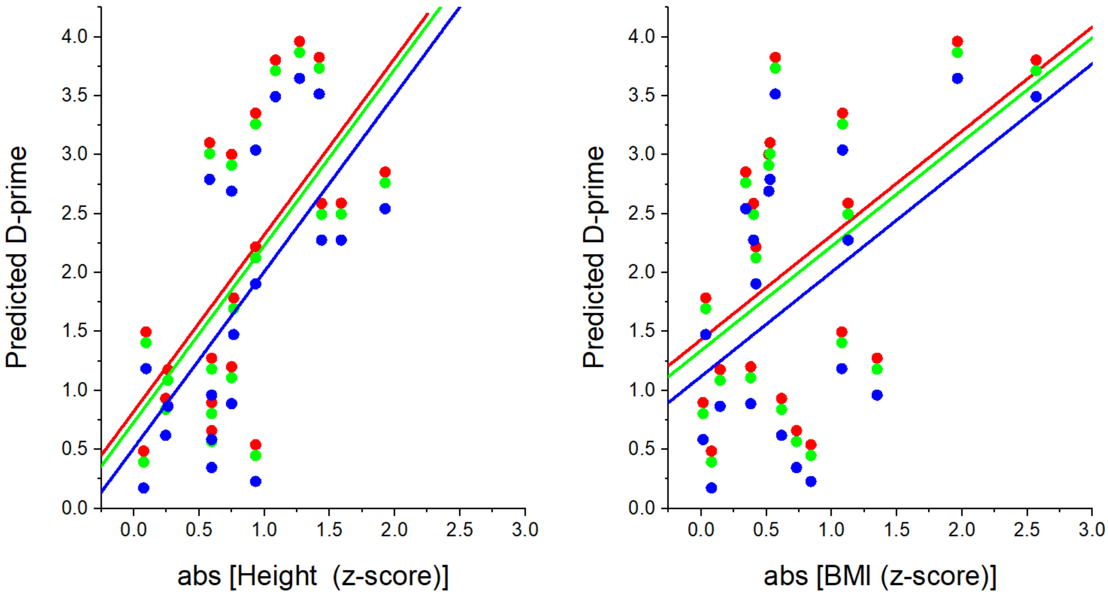


Figure 5.7 *Illustrates predicted model fit of Dprime in relation to absolute z-scores of height (left panel) and BMI (right panel); red lines represent 2-avatar condition, green lines represent 4-avatar conditions, and blue lines represent 6-avatar condition.*

Response bias (C)

The Type 3 tests of fixed effects for response bias showed a statistically significant fixed effect of condition (number of avatars), $F(2,38) = 27.91$, $p < .001$. However, we did not find a main effect of unusualness of height, $F(1,38) = .24$, $p = .628$ or unusualness of BMI, $F(1,38) = 2.45$, $p = .135$. This suggests that the number of avatars present in the scene lowered the participants' bias (C), meaning that participants were more likely to say 'yes'. However, as reported above in **Table 5.4** sensitivity (Dprime) did not change, despite this criterion shift.

Post-hoc pairwise comparisons of LSmeans, controlled for multiple comparisons, showed that bias was statistically significantly different between: the 2- and 4-avatar conditions: $t(38) = 5.02$, $p < .001$; the 2- and 6-avatar conditions $t(38) = 7.30$, $p < .001$; and the 4- and 6-avatar conditions $t(38) = 2.28$, $p = 0.02$.

This is illustrated in **Figure 5.8** below, which shows the outcome of our linear mixed effects model for bias (C) demonstrating that as more avatars are present in the scene, C becomes negative.

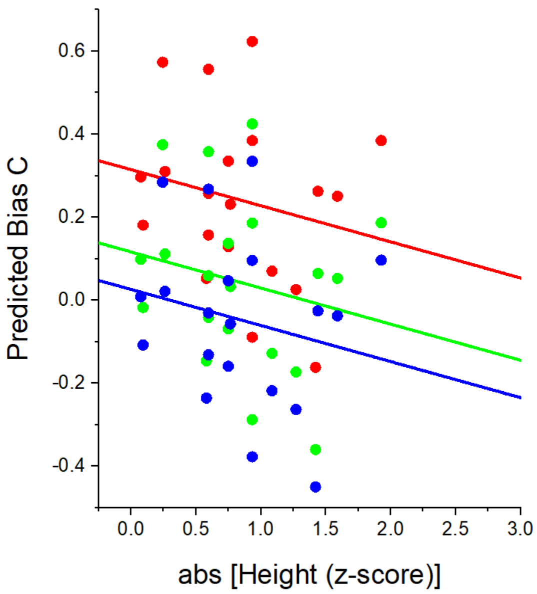


Figure 5.8 *Illustrates predicted model fit of bias (C) in relation to absolute z-scores of height; red lines represent 2-avatar condition, green lines represent 4-avatar conditions, and blue lines represent 6-avatar condition*

Study 5 Discussion

We conclude that, based on group averages, our participants can successfully identify their personalised avatars (indexed by Dprime) when the only information available to them was about their body shape and size; (i.e. they did not have access to information about their face, skin tone or hair). However, we also found substantial individual variation much of which was attributable to how salient an individual's height was with respect to the sample of avatars presented. In each condition, between six and seven of the twenty participants failed to identify their avatar with an accuracy above 60%. Of those, 3, 4 and 6 participants were equivalent to or less than 50% accurate for the 2-, 4- and 6-avatar conditions respectively. Two participants performed poorly across all conditions, and three across two conditions.

5.4 Study 6 – comparison of psychophysical tasks in 2D and VR

The previous study confirmed that our personalised, body only avatars, contain sufficient information for most participants to be able to detect their presence in the scene. Next, we needed to compare accuracy and precision of performance on the Method of Adjustment task in 2D with that in immersive Virtual Reality for a standard model and personalised avatars.

5.4.1 Method

The methods for participant recruitment and experimental procedures were approved by the Faculty of Health and Life Sciences Ethics Committee at Northumbria University.

Participants

We recruited 45 eligible female participants, including the 20 participants from study 5. Five participants did not return for the second session. The remaining 40 participants (M_{age} = 23.33, SD_{age} = 4.66) fulfilled the following eligibility criteria: they were female (as assigned at birth), aged 18 - 35, fluent in English, with no history of eating disorders, and with normal or corrected to normal visual acuity. Potential participants were advised not to sign up for the study if they suffered from motion sickness. Participants were recruited on a voluntary basis from the population of undergraduate and postgraduate students, staff at Northumbria University, and the general population in Newcastle upon Tyne (by word of mouth). All gave written consent to take part in the study. Undergraduate students were given SONA credits for taking part, other participants were not reimbursed in any way for their time. **Table 5.6** shows participant characteristics.

Table 5.6. Participant characteristics for study 6, n=40

	M	*SD*	*Range*	
			Actual	*Potential*
Participant characteristics				
Age (years)	23.33	4.66	18 – 35	18 – 35
BMI (kg/m^2)	22.41	3.62	15.97 – 31.35	
Depression and self esteem				
RSE	19.80	4.48	8 – 28	0 – 30
BDI	10.92	9.02	0 – 40	0 – 63
Body shape and eating concerns				
BSQ	36	15.93	16 – 83	16 – 96
EDE-Q restraint	1.20	1.14	0 – 3.60	0 – 6
EDE-Q eating concern	.60	.82	0 – 4	0 – 6
EDE-Q weight concern	1.53	1.13	0 – 4.8	0 – 6
EDE-Q shape concern	2.12	1.53	0 – 5.50	0 – 6
EDE-Q global	1.36	1.13	0 – 4.48	0 – 6

Note: BDI = Beck Depression Inventory , RSE = Rosenberg Self-Esteem Scale, EDE - Q = Eating Disorders Examination Questionnaire with subscales, BSQ = Body Shape Questionnaire

Measures

Anthropometric measurements were administered in the same manner as study 5. We also used the MoA task as described in Chapter 2: (pp. 59 - 63). Participants completed questionnaires as described in Chapter 2: (i) Rosenberg Self-Esteem Scale (RSE; Rosenberg, 1965); (ii) Beck Depression Inventory (BDI; Beck et al., 1996); (iii) Body Shape Questionnaire (BSQ; Evans & Dolan, 1993); (iv) Eating Disorders Examination Questionnaire (EDE-Q; Fairburn & Beglin, 1994). Cronbach alpha was calculated for each measure, and all produced excellent internal consistency: RSE α = .853; BSQ α = .956; EDE-Q α = .953; and BDI α = .921

Method of Adjustment task in Virtual Reality

We used a novel Method of Adjustment (MoA) task in Virtual Reality that was created as part of the VR software suite. We used the same VR set up as in Study 5. In this study, participants completed two versions of the MoA task in VR: one with a standard model adjusted to the participant's height, and one with a bespoke avatar of the participant. Each model was presented life-sized (scaled 1:1) in 3D. The personalised models were created as described above in the Avatar creation section.

Each participant carried out 20 trials with their own bespoke avatar, and 20 trials with a standard model adjusted to match their height. The order in which each task was carried out was randomised across participants.

At the start of each trial, a single body model appeared in front of the observer at a distance of 1.8m. The model's BMI was set alternately to either its maximum (BMI of 36.1) with the response slider positioned on the extreme right of its range, or its minimum (BMI of 15.1), with the response slider positioned on the extreme left of its range. **Figure 5.9** shows examples of the slider position and corresponding body size of the standard model.

During a trial, participants used the Oculus Touch controllers to move the slider and match the stimulus body to the body size they believed they had, whereupon they 'hit' a virtual box counter. The slider was then reset, and the next trial began. Mechanistically, the slider dynamically adjusts the blend weights of the mass and tone morph targets. When the slider is moved leftward away from 0, all the set morph weights of the standard model/avatar are reduced, while the morph values of the minimum weight target (BMI of 15.1) are increased. When the slider is moved rightward away from 0, all the set morph weights of the standard model/avatar are reduced, while the morph values of the maximum weight target (BMI of 36.1) are increased. In this way a seamless blend between standard model/customised avatar and the minimum or maximum models was achieved.

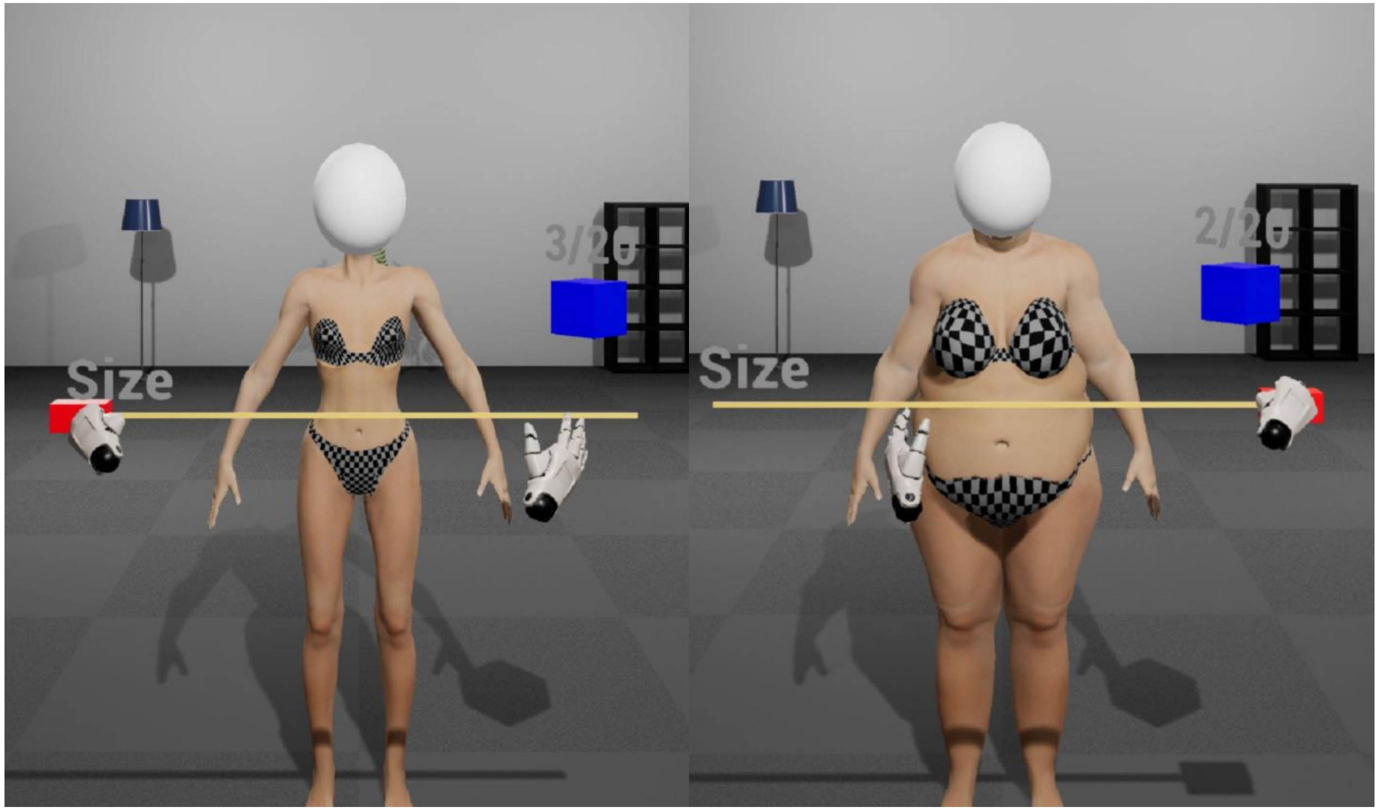


Figure 5.9 *Shows examples of the slider position and corresponding body size of the standardised stimuli.*

Procedure

The study was carried out in two sessions. During the first session the participants read the Information Sheet, consented to take part, and had their height and weight measured. Their photographs were taken as described in the Avatar Creation and Validation section (pp. 142-144). This session took about 30 mins per participant. The avatars were made as soon as possible, typically within two days. Participants were then asked to return for the second session, which they did typically within a week. In the second session the participants completed the psychometric measures first then completed the three versions of the MoA task in randomised order.

Treatment of data

On each trial we calculated the percentage error for that trial as follows:

(estimated BMI – actual BMI) / actual BMI x100

Here we adopt the following definitions for precision and accuracy (Menditto, Patriarca, & Magnusson, 2006). Precision is defined as variation between trials, (i.e. how close the measured values are to each other). It amounts, therefore, to the repeatability or reproducibility of the measurement. Precision is said to be high when the variability of judgements is small. Accuracy expresses how close the measured values are to the true value. Accuracy is said to be high when the central tendency of the judgements is close to the actual value, (i.e. to be accurate is to be correct). Numerically, we defined accuracy as the mean percentage error across all 20 trials, and precision as the standard deviation of percentage error.

5.4.2 Results

Univariate statistics

Table 5.7 Method of adjustment mean accuracy and precision in 2D and VR, n=40

Task	Accuracy (% error)		Precision (%error)	
	M	SE	M	SE
2D (MoA): standard model	7.10	2.28	4.80	0.40
VR: standard model	-6.25	1.89	3.06	0.38
VR: avatar	-0.05	1.58	2.65	0.33

Table 5.7 shows mean accuracy and precision across the three different MoA tasks. With respect to accuracy, across the sample, participants over-estimated their size when performing the task in 2D. With a standardised model in VR, participants under-estimated their size, while they appeared to be quite accurate with a personalised avatar in VR. With respect to precision, it appears that participants responded more precisely in VR than with the 2D stimuli.

Multivariate statistics

Ultimately, we wanted to test whether accuracy and precision were influenced not only by measurement methods, but also by the effects of participants' psychological state and their actual BMI (i.e. 2D, VRstd and VRavatar). In order to avoid the possibility of introducing substantial variance inflation, we first checked for evidence of co-linearity amongst the psychometric variables. **Table 5.8** shows the Pearson correlations between the psychometric variables, all of which were statistically significant at $p < .01$.

Table 5.8 Pearson correlations between psychometric measures from the whole sample in study 6, n=40

	BDI	EDE-Q res	EDE-Q eat	EDE-Q sc	EDE-Q wc	EDE-Q	BSQ
RSE	-0.77*	-0.52*	-0.64*	-0.68*	-0.57*	-0.65*	-0.68*
BDI		-0.42*	0.62*	0.53*	0.49*	0.55*	0.64*
EDE-Q res			0.64*	0.86*	0.80*	0.91*	0.82*
EDE-Q eat				0.69*	0.73*	0.97*	0.78*
EDE-Q sc					0.92*	0.97*	0.90*
EDE-Q wc						0.96*	0.90*
EDE-Q							0.94*

Note: RSE = Rosenberg Self-Esteem Scale, BDI = Beck Depression Inventory, EDE-Q = Eating Disorders Examination Questionnaire global score, and EDE-Q subscales: res = restraint, eat = eating concern, sc = shape concern, wc = weight concern, BSQ = Body Shape Questionnaire

** = significant at p < .01*

Given these substantial correlations, we used PROC FACTOR in SAS v9.4 (SAS Institute, North Carolina, USA) to carry out a principal component analysis with Varimax rotation in order to identify significant latent variables in the psychometric data. We then used the factor scores from these latent variable(s) in our statistical models. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy (which indicates the degree of diffusion in the pattern of correlations) was 0.68, indicating a (barely) acceptable sample. One factor had an Eigenvalue greater than Kaiser's criterion of 1, which explained 78% of the variance. The scree plot showed an inflection, i.e. Cattel's criterion which also justified retaining just the one factor. The residuals were all small, and the overall root mean square off-diagonal residual was 0.122, indicating that the factor structure explained a reasonable proportion of the correlations. The factor loadings for RSE, BDI, EDEQ and BSQ were: 0.87, 0.83, 0.90 and 0.93 respectively. This latent variable, referred to henceforth as PSYCH, represents a combination of the attitudes thought to contribute to body size disturbance: disturbed attitudes to eating, weight, and shape.

Finally, we used PROC MIXED in SAS v9.4 (SAS Institute, North Carolina, USA) to build separate linear mixed effects models for accuracy and precision. The fixed effects in each model included: i) condition (i.e. 2D, VRstd and VRavatar), ii) PSYCH and iii) actual BMI. We also tested two- and three-way interaction terms. In addition, we permitted individual variation at the intercept level for each observer, by including a random effect with an unstructured variance-covariance matrix in each model.

Precision

The Type 3 test of fixed effects for precision showed a statistically significant fixed effect of condition $F(2,78) = 16.12$, $p < .001$, a marginal effect of PSYCH $F(1,78) = 3.19$, $p = .07$, and no significant effect of participants' BMI $F(1,78) = 0.21$, $p = .65$. This suggests that precision of participants' responses depended only on the type of task that they carried out.

Post-hoc pairwise comparisons of LSmeans controlled for multiple comparisons showed that precision was statistically significantly poorer when comparing performance between the 2D and VR avatar conditions $t(78) = 5.35$, $p < .001$, as well as the 2D and standard model VR conditions $t(78) = 4.32$, $p < .001$. However, precision was comparable between the avatar and standard model conditions $t(78) = -1.04$, $p = .303$

Accuracy

The Type 3 test of fixed effects for accuracy showed a statistically significant fixed effect of condition $F(2,78) = 21.72$, $p < .001$ and PSYCH $F(1,78) = 14.96$, $p < .001$, but not participants' BMI $F(1,78) = 0.12$, $p = .732$. There was no significant interaction between condition and PSYCH. This suggests that the accuracy of participants' responses depended on both the type of task the participants carried out and their psychological state.

Post hoc pairwise comparisons of LSmeans controlled for multiple comparisons showed that accuracy was statistically significantly poorer when comparing performance between the 2D and VR avatar conditions $t(78) = 3.53$, $p < .001$, as well as the 2D and standard model VR conditions $t(78) = 6.59$, $p < .001$; and VR avatar and VR standard model conditions $t(78) = 3.06$, $p < .001$.

LSmeans for accuracy were then computed from the linear mixed effect model with PSYCH set at -1SD (i.e. a low score) and +1SD (i.e. a high score). **Table 5.9** below presentd the outcome and shows the uniform influence of PSYCH across all measurements, this is illustrated in **Figure 5.10** overleaf; this is a result entirely consistent with previous literature (Cornelissen et al., 2017; 2015) and results in Chapter 3.

Table 5.9 Method of Adjustment (MoA); effect of PSYCH on Accuracy (% error), n=40

Task	PSYCH -1SD		PSYCH 0SD		PSYCH +1SD	
	LSmean	*SE*	*LSmean*	*SE*	*LSmean*	*SE*
2D (MoA): standard model	1.87	2.22	7.10	1.78	12.33	2.22
VR: standard model	-11.48	2.22	-6.25	1.78	-1.02	2.22
VR: avatar	-5.28	2.22	-0.05	1.78	5.19	2.22

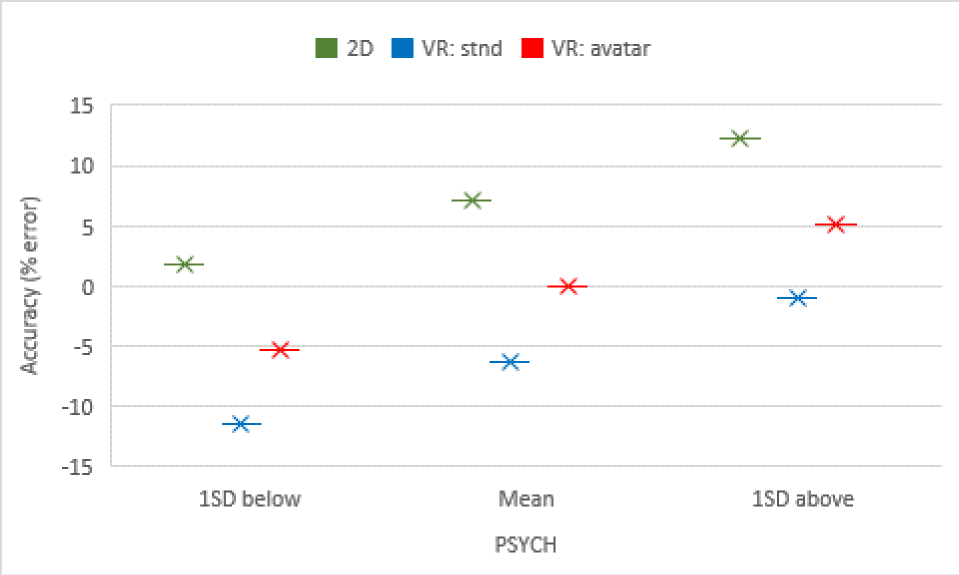


Figure 5.10 *Illustrates the influence of PSYCH across the three tasks.*

5.5 Discussion

In study 5 we wanted to know whether the avatars we created represented each participant's body shape and size adequately. Therefore, we investigated their sensitivity to identity, (i.e. their ability to detect the presence of their own bespoke avatar among other avatars). The results showed that when averaged across the sample, participants' sensitivity (Dprime) remained high, demonstrating that they were able to perform the task accurately, (i.e. with few misses or false alarms). However as discussed earlier this simple description is potentially misleading because ~20% of the sample performed at, or close to, chance. Moreover, the likelihood of participants correctly identifying their avatar was strongly dependent on how unusual their height was for the cohort of avatars. In addition, we found that as more avatars were added to the scene, participants' bias changed, meaning that they were more likely to say 'yes, I am in the scene'. This latter result may have a straightforward explanation, consistent with what one might intuitively expect. Up to a limit, perhaps one should expect in such a yes-no task that participants would be more likely to believe that they are present in the scene as more and more people are present.

One implication of these identity data is that if anonymised avatars are to be used for a VR body size estimation task, then perhaps participants should be pre-tested for their ability to identify themselves in the scene, as an initial check. Otherwise, if participants are not able to meet this criterion, it may be much harder to interpret any body size estimation they make. In short, if a participant is not convinced that the image they are being presented is themselves, what body size comparison are they actually making? To our knowledge, this is the first time that researchers have addressed participants' ability to correctly identify an avatar of themselves in immersive VR. Given that we did not demonstrate uniform success across all participants, further research is needed to understand the consequences of this finding.

In study 6, participants estimated their body size using the method of adjustment task using the same 2D stimuli as in earlier chapters. The same participants also made the same judgements in a novel method of adjustment task in VR, with both a 3D standard model as well as a 3D bespoke avatar. We found that women in this study were accurate in their body size estimations when the task was performed with a personalised avatar in VR as compared to a standard model, where they systematically under-estimated their body size. However, performance with the standard stimuli showed over-estimation in 2D and under-estimation in VR.

In study 6, the standard model used in the 2D MoA task was different from the standard model in the VR MoA task. Clearly, this means that a definitive comparison between body size estimation in 2D and 3D/VR is not feasible yet because the underlying model in the stimuli covaries perfectly with stimulus presentation method. What is needed, and future research will provide, is a comparison between 2D and 3D/VR presentations of stimuli built from the *same* model. We did not conduct this, as this would have meant participants carrying out 5 experimental conditions in study 6, which we did not think was reasonable. We therefore chose to use the same 2D MoA task that we used in our earlier investigations, as it allowed us to place the results of study 6 in the context of our prior findings. To this extent, we observed ~7% over-estimation of body size using the 2D MoA in study 6, which was independent of participants' BMI, and is consistent with the ~5% over-estimation we observed in Chapter 3 (see section 3.3.3 and **Figure 3.5**) using the same task. Assuming that future control studies replicate this result, a potential explanation for why participants over-estimate their size when the task is carried out with 2D stimuli on a monitor is that distortions (e.g. flattening and slimming effects) inherent to non-orthostereoscopic image capture and projection occur in 2D (Harper & Latto, 2001). This would mean that the image appears smaller to the participants than the actual dimensions of the model it presents. Again, further studies need to be conducted to test this hypothesis.

The majority of previous studies have not addressed the distinction between size estimation in 2D and 3D. Mölbert et al. (2017b) is the only study we are aware of, where participants expressed their body size with MoA, using avatars; where the stimulus was also presented life-sized in 3D (stereoscopically, rather than VR), as well as on a conventional 2D monitor. These authors have found that both control participants and anorexic participants have under-estimated their size regardless of mode of presentation. Evidently, further investigation of the mode of presentation is needed.

A direct comparison of participants' performance with the standard model and their avatars in 3D/VR is feasible however. In Study 6, participants judged their body size accurately when presented with their avatar, and systematically under-estimated when presented a standard model. A potential explanation for the accurate performance with avatars is that participants no longer have to perform some sort of mental transformation between a standard model and the underlying body shape they believe themselves to have, before being able to compare them. Effectively, by using a bespoke avatar, this (assumed) component of the 'work' is done for them. Consistent with such an interpretation are some of the anecdotal comments made by participants; e.g. 'it's better when it's life sized, it looks more like me'. They also commented on how they identified more with the avatar and found the task easier; e.g. 'the belly is like mine now, but other parts are not, but my belly is more important'.

One possible explanation for the systematic under-estimation of body size with the standard 3D model in VR is simply that it is unusually curvaceous. When un-adjusted (i.e. slider is set to 0), the model has a low waist-to-hip ratio (WHR) of 0.68, which is not typical for UK women. A meta-analysis using Health Survey for England data reported an average WHR of 0.87 (Czernichow, Kengne, Stamatakis, Hamer, & Batty, 2011). We know from the Bubble masking study in Chapter 4 that women make use of torso edge information around the waist and hips when they judge their body size. If the waist of the standard model appears unusually small to most participants, perhaps they choose to focus more attention on the hip edges below the waist when matching their mental representation of their own body size with what is presented on screen. Matching in this way will lead to a stimulus image choice that will have a narrower waist than reality, and hence an under-estimate of BMI. This potential explanation needs to be investigated, along with an investigation of differences in object size estimation in 3D VR and 2D.

5.6 Body ownership, point of view and size estimation

As described in the Introduction, the ultimate question we need to ask is whether body size estimation is the same or different when participants make these judgements from a first person or third person point of view. To address this question, we need to create the most ecologically valid situation for such measurements which would be equivalent to a participant looking in the mirror, dynamically manipulating the size of the image in the mirror to match the body size the participant feels themselves to have. To move towards this goal, we have shown that most participants can identify their own body-only avatar, and that body size estimates from a third person perspective, made using that avatar, are accurate.

To address our final goal, and make the same measurement in first person perspective, the VR software created for this project allows manipulation of point of view, along with illusory body ownership to explore these possibilies. As we go on to discuss, however, we experienced technological difficulties that we were unable to overcome within the timeframe of this project.

5.6.1 Method

Virtual reality 1POV task

Piryankova et al. (2014b) showed that in virtual reality body ownership can be achieved without synchronous/asynchronous touching when they used real time motion tracking. The integration of proprioceptive and somatosensory feedback of their actual body, the VR visual stimuli and head tracking seemed sufficient to induce presence in their participants. Therefore, we decided to use the Perception Neuron motion tracking equipment to achieve a sense of body ownership over stimuli, as well as to increase the ecological validity of our paradigm. Perception Neuron requires the participant to wear velcro straps on their feet, knees, thigs, head and arms, as well as a shoulder harness and gloves (see **Figure 5.11** overleaf). Small chips are attached to the straps that track movement in real time, each chip houses an Inertial Measurement Unit (IMU) with a gyroscope, accelerometer, and magnetometer; each IMU has 6 degrees of freedom (roll, pitch and yaw). The Perception Neuron sensor units output data at 60 frames per second, with 8 millisecond delay. The data stream is channelled to a hub, from which it is transferred to a computed via a universal serial bus 2.0 cable. The Perception Neuron then connects to the AXIS Neuron software for calibration and management of the system. The data then streams into the bespoke software by VRI Ltd.

Simultaneously, the participants were going to wear the Oculus Rift headset (1080 x 1200, global refresh rate of 90Hz). In virtual reality the participant were going to see the body from a first-person perspective, they could do so by looking down or looking in a virtual a mirror positioned in front of the participant.

Figure 5.11 *Perception Neuron motion tracker.*

5.6.2 Future directions

This study was going to investigate size estimation as carried out in first person and third person perspectives, using method of adjustment. The bespoke VR software was develop specifically for this purpose. We were intending to trial the possibility of pairing the Perception Neuron and Oculus Rift to deliver our paradigm. Unfortunately, once the software was built and we were beta testing the set up, it became apparent that environmental interference was affecting the tracking on the Perception Neuron too much, which caused the virtual body to drift. We plan to finesse our set up and use a different method of body tracking, not prone to environmental interference, such as the Vive trackers. The Vive motion trackers can be attached to participants' feet and hips, along with head tracking (via the HMD) and hand tracking (via controllers), thus full body movement can be achieved with inverse kinematics.

Chapter 6: Study 7 - The effects of perceptual training on size estimation, a replication and extension in immersive virtual reality.

In this chapter, we attempt to replicate and extend the results of Gledhill et al. (2016) in women who have heightened body shape concerns, using immersive virtual reality.

6.1 Introduction

Section 1.6 of the Introduction described existing treatment approaches for eating disorders and their limited success, as reflected in high relapse rates (Berkman et al., 2007; Castrol et al., 2004; Channon & DeSilva, 1985; Herzog et al., 1999; Keel et al., 2005; Strober et al., 1998;). Body image distortion has often been identified as a key predictor of relapse and poor outcomes (Casper et al., 1979; Castro et al., 2004; Channon & DeSilva, 1985; Farrell, Shafran, & Lee, 2006). In particular, interventions that do not address over-evaluation of shape and size have been associated with increased risk of relapse (Fairburn et al., 2003). The cognitive-behavioural (CBT) interventions specifically designed to treat body image developed by Rosen (1997) and Cash (1995) are the most commonly used approaches. Cognitive behavioural therapy aims to challenge and change three key aspects: body size perception (via mirror exposure), cognitive dysfunctions (thoughts, beliefs and attitudes) and behaviour (avoidance, body checking) through interventions such as psychoeducation, self-monitoring, cognitive restructuring, mirror exposure and desensitisation, and problem solving (Farrell et al., 2006; Jarry & Cash, 2011). Mirror exposure, however, does not directly address size over-estimation.

Other talking therapies may also be used as described in section 1.6 of the Introduction, as well as a number of adjunct approaches. For example, improving body functionality which shifts focus on to what one's body is capable of, and away from appearance (Alleva, Martijn, et al., 2015, 2013). To challenge the impact of thin-ideals, media literacy training can be used (Ginis & Bassett, 2011; Wilksch, Tiggemann, & Wade, 2006) and preventative health education programmes have also been tried in the attempt to enhance self-esteem and reduce eating pathology (O'Dea & Abraham, 2000; Winzelberg et al., 2000; Zabinski et al., 2004). However, a meta-analysis conducted by Alleva, Sheeran, et al. (2015) revealed that once corrections for bias (both within and across studies) in the data were applied, the effect sizes of these treatments were relatively small. This highlights the need for novel, high-quality interventions to address negative body image.

With this aim in mind, in Chapter 1 we described studies by Gledhill et al. (2016) and Szostak (2018). In their first study, Gledhill et al. (2016) recruited women who had heightened body shape concerns, but no specific history of eating disorders. They used a novel perceptual training technique to increase observers' subjective categorical boundaries for what constituted a thin versus a fat body, towards fatter bodies. This perceptual shift was followed by reductions in psychological concerns about body shape, weight and eating which persisted for two weeks post-training. Gledhill et al. (2016) found similar effects in a sample of women with a history of anorexia, although the perceptual changes took longer to emerge. In this case, the reductions in psychological concerns about body shape, weight and eating persisted for up to a month from initial testing. Using a more rigorous psychophysical testing procedure, Szostak (2018) replicated these results for women with heightened body shape, weight and eating concerns, but no specific history of eating disorders. The success of these two studies demonstrates that this approach may be a viable adjunct technique to support recovery in eating disorders.

Owing to the immersive nature of the virtual reality experience, researchers have asked if its benefits could be applied to assessment and treatment of body image as outlined in the Introduction of Chapter 5. Early steps have been taken in such applications of virtual reality for treating obesity (Manzoni, et al., 2016; Cesa et al., 2013) and eating disorders (Basshetta, Baruffi, & Molinari, 2001; Perpiñá, Botella, & Baños, 2003; Perpiñá et al., 1999; Riva, 1998). For example, Perpiñá et al. (1999) delivered body image treatment adapted from CBT described originally by Cash (1995). The authors found that eating-disordered participants showed a significantly greater improvement on body image measures, as well as anxiety and depression, when the body image treatment was delivered with a virtual reality component, compared to typical treatment. Virtual reality has further shown its potential for applicability in body image/ eating disorders treatment. Perpiñá et al. (2003) and Marco, Perpiñá, and Botella (2013) have shown that participants whose treatment incorporated a body image specific virtual reality component alongside CBT, improved more than the group without such a component. Furthermore, improvement was maintained post-treatment and at one year follow up. Similarly, Manzoni et al. (2016) compared: a standard behavioural program, a standard behavioural program plus CBT, a novel standard behavioural program plus VR-enhanced CBT approach for morbid obesity. While all approaches were successful at discharge from inpatient treatment, the VR-enhanced CBT was successful at follow up, while those in standard treatment regained most of the originally lost weight.

Systematic reviews have concluded that the results of early virtual reality studies for treatment of body image, eating disorders and obesity provide promising results, and indicate that large controlled trials of clinical samples are warranted (Ferrer-Garcia et al., 2015; Ferrer-Garcia, Gutiérrez-Maldonado, & Riva, 2013; Koskina, Campbell, & Schmidt, 2013)

Importantly, virtual reality technology has improved substantially in the last few years. The recent technological advances have made it possible to present stimuli in realistic, ecologically valid fashion with no perceptible time lag. Therefore, it is of interest to take advantage of the current technology and further explore the applicability of virtual reality to the treatment of body image, particularly its perceptual component. Critically, however, it is essential to carry out such a study in a way that compares what can be achieved with cheaper equipment in 2D, versus the more expensive virtual reality option. For these reasons, in the current study we ensured that our control and intervention conditions carried out in virtual reality should be directly comparable to the equivalent conditions carried out in 2D by Gledhill et al. (2016).

However, what is effective and compelling for 2D stimulus presentations is not necessarily so for virtual reality. For example, literature on social comparison theory suggests that women evaluate and compare themselves against other women in real-life situations with the potential for improving their attractiveness (Bailey & Ricciardelli, 2010; Cundall & Guo, 2015; Festinger, 1954; Gervais, Holland, & Dodd, 2013; Leahey et al., 2007). Even if it is a “glance-over”, this process may take time, and certainly longer than the brief 150ms presentations that were used by Gledhill et al. (2016). Therefore, in the current study, we added a third condition, referred to as the ‘new intervention condition’, where the stimuli were presented to the participant for as long as it was necessary for participants to make a decision. We felt this was justified from two points of view: i) no clear, a-priori justification was given in Gledhill et al. (2016) for the brief stimulus presentations, therefore there was no compelling reason, aside from replicating their experimental conditions, for being completely bound by this constraint; ii) from an empirical point of view, we wanted an intervention that felt VR friendly.

6.2 Method

The experimental procedures and methods for recruitment and data collection for this study were approved by the Faculty of Health and Life Sciences Ethics Committee at Northumbria University. The VR software for this study was created by Andrew Irvine at Virtual Research Innovations, Ltd.

6.2.1 Participants

Participants were recruited from undergraduate and postgraduate student populations across various faculties at Northumbria University. To be eligible to take part in the study, participants had to be female (as assigned at birth), aged 18-35, fluent in English, and have no history of eating disorders. Potential participants were asked to complete an online version of the Body Shape Questionnaire (BSQ; Evans & Dolan, 1993). The questionnaire measures attitude towards body shape and size. A score of 66 and above indicates “marked concern with shape” (Taylor, 1987) and is considered clinically concerning. However, to be consistent with the study design of Gledhill et al. (2016), we accepted those participants who scored 60 or above, i.e. “substantial, yet sub-clinical body shape concerns” (Taylor, 1987). Ultimately, we wanted to compare effect sizes in this new study with those of Gledhill et al. (2016) who found clinically meaningful reductions in EDE-Q scores with a sample size of 20 participants per group, at a power of 0.9 with an alpha value of 0.05. Therefore, like Gledhill et al. (2016) we set out to recruit 20 participants into each condition. We collected online BSQ responses from 247 individuals, of whom 71 met the criteria for study inclusion, (i.e. score of 60 or above). Of those, 25 participants did not respond to invitations to attend the training, 46 attended the lab, and one participant did not complete the training. Participants who completed the pre-screen questionnaire were awarded 2 SONA points for their time. Participants who completed the full training received a £20 Amazon gift vouchers as well as 20 SONA points. Participants were randomly assigned to one of three study conditions and their characteristics are presented in **Table 6.1.** To date, we have not yet been able to collect 20 participants per condition. At the time of writing, we had 15 participants per condition, but intend to continue recruiting to 20 participants. This is addressed further in the Discussion.

Table 6.1. Participant characteristics, questionnaire data and pairwise comparisons from the participants in study 7

	Intervention old (n=15)		Control (n=15)		Intervention new (n=15)		Cont v Intr old	Cont v Intr new	Int new v Intr old
	M	*SD*	*M*	*SD*	*M*	*SD*	*p*	*p*	*p*
Age	21.20	2.76	22.27	4.45	22.00	3.91	.436	.862	.522
BMI	25.93	4.38	27.96	6.78	26.45	4.76	.337	.484	.757
BSQ	71.2	11.80	68.67	12.5	66.85	7.97	.603	.346	.125
EDE-Q	3.63	0.72	3.37	0.83	2.93	1.13	.357	.241	.052
EDE-Q res	2.76	1.18	2.87	1.16	2.88	1.25	.877	.904	.789
EDE-Q eat	2.72	1.20	2.09	1.31	1.97	1.24	.183	.799	.105
EDE-Q sc	4.84	0.64	4.50	0.71	3.78	1.35	.176	.076	.010
EDE-Q wc	4.21	0.81	4.05	0.76	3.11	1.36	.581	.026	.010
RSE	13.27	3.99	14.00	4.28	16.20	4.92	.631	.201	.083
BDI	27.6.	10.38	24.93	7.80	16.27	10.69	.433	.017	.006

Note: BSQ = Body Shape Questionnaire, EDE - Q = Eating Disorders Examination Questionnaire with subscales: res = restraint, eat = eating concern, wc = weight concern, sc = shape concern

6.2.2 Materials

Psychometric and anthropometric measures

Participants' attitudes towards body shape/size, weight and eating were repeatedly (day 1, 4 and 14) assessed with the EDE-Q (global and sub-scales) and BSQ, along with their tendency towards depression, and their self-esteem using the self-report questionnaires described in Chapter 2: General Methods (pp. 59 - 63).

Participants' body mass index (BMI) was calculated from their weight and height obtained with a set of calibrated scales and a stadiometer, respectively.

Stimulus creation

Based on a number of pilot experiments, Gledhill et al. (2016) selected 15 2D CGI models for their stimulus sequence, whose BMIs increased from 15.45 to 33.70 in equal steps of 1.30 BMI units. Therefore, for the current study, we used our VR software (as described in Chapter 5) to create a sequence of fifteen 3D models that matched the same BMI increments (see Chapter 5 for further details). **Table 6.2** illustrates the relationship between the BMIs of the stimuli and the World Health Organisation's BMI classification (World Health Organisation, 2003). **Figure 6.1** overleaf shows actual models.

Table 6.2. Estimated body mass index for the fifteen body models and BMI categories.

Body model	Estimated BMI	BMI category
1	15.45	Severely underweight
2	16.75	Underweight
3	18.06	Underweight
4	19.36	Normal
5	20.66	Normal
6	21.97	Normal
7	23.27	Normal
8	24.57	Normal
9	25.88	Overweight
10	27.18	Overweight
11	28.49	Overweight
12	29.79	Overweight
13	31.09	Obese
14	32.40	Obese
15	33.70	Obese

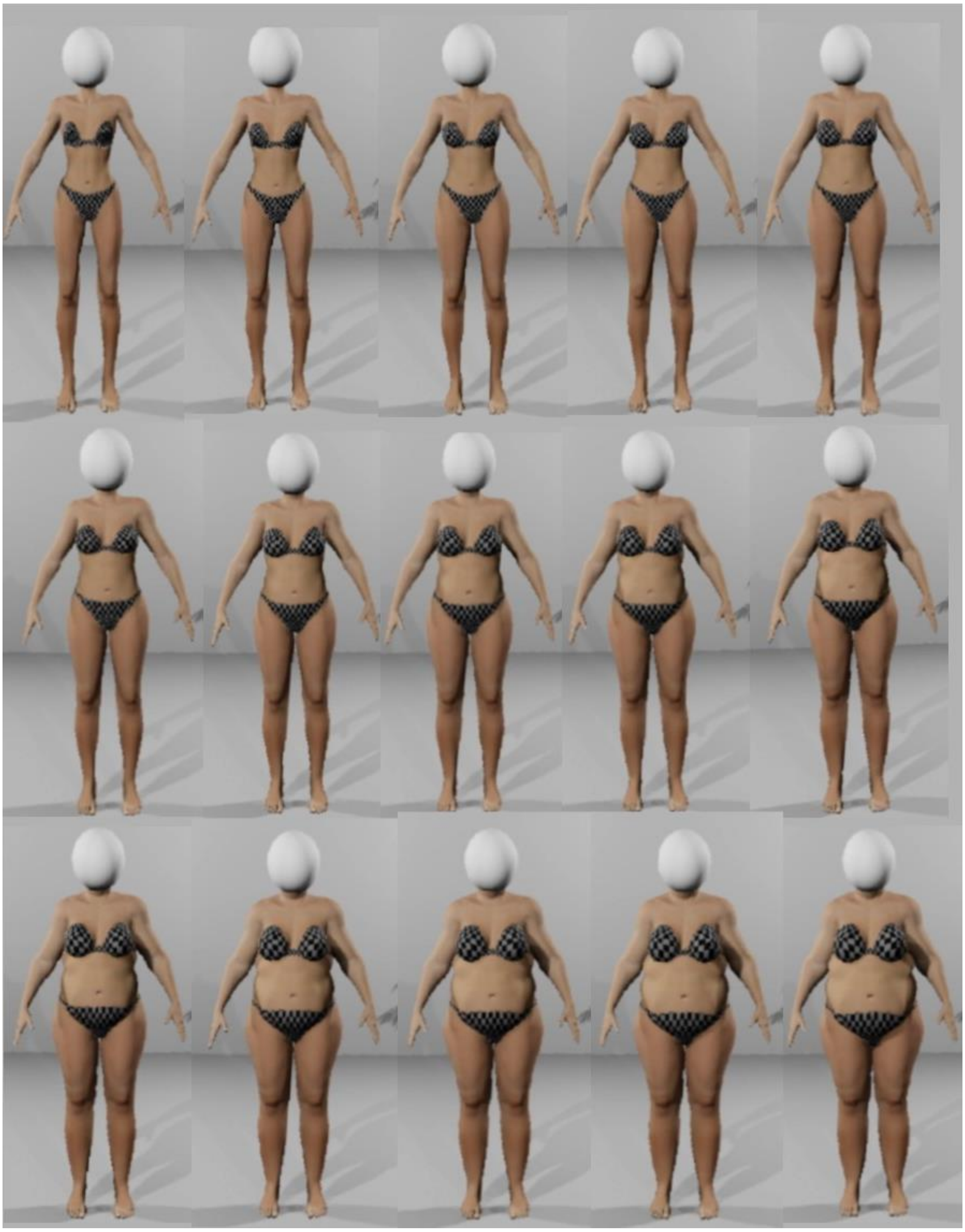


Figure 6.1 *Shows all of the models: top row shows models 1 - 5 (BMIs of 15.45 - 20.66), middle row shows models 6 - 10 (BMIs 21.97 – 23.27), and bottom row shows models 11 - 15 (BMIs of 28.49 – 33.70).*

The perceptual training paradigm

Like the Gledhill et al. (2016) study, our perceptual training programme was carried out over 4 days, however, all stimuli were presented in VR. At the start of each day, all participants carried out a baseline estimate of their categorical boundary for that day. This was followed by the perceptual training. For this, participants were randomly assigned to one of the three conditions: (i) control intervention, (ii) old intervention (i.e. stimuli presentation replicating the settings of Gledhill et al. (2016) as closely as possible) and (iii) new intervention (i.e. stimuli presentation optimised for VR).

The control and the old intervention conditions were set up to match as closely as possible the control and intervention conditions in the 2D study of Gledhill et al. (2016). Specifically, the sequence of events visible in the VR headset with respect to the structure of the fixation cross, the visual angle subtended by the figure in the scene, and the size and structure of the mask. We also matched the timings of all events as closely as possible. Accordingly, each trial of the old intervention and control conditions began with a central fixation cross which was shown for 1500 - 2500ms (randomly jittered). The cross was then replaced by a presentation of a body model (for 150ms), followed immediately by a visual noise mask (for 150ms). Two virtual boxes then appeared in front of the participants, one read “fat” and the other “thin” (i.e. 2-alternative forced choice) and the participants responded using Oculus Touch controllers by ‘hitting’ the box they chose. The next set of trials followed once a decision was made.

The new intervention was designed to be optimized for VR presentation. Specifically, as argued in the Introduction, to take full advantage of the potentially improved presentation (3D, life sized), a quick presentation akin to that of Gledhill et al. (2016) felt too abrupt, and on pilot testing, somewhat visually confusing. Therefore, we added a new intervention condition, which removed the time constraints and the visual noise mask. Instead, at first a fixation cross appeared (1500 - 2500ms, randomly jittered), followed by the body model which remained visible for as long as it took participants to make a decision. This sequence of events felt much more natural, and therefore VR friendly. This long/untimed exposure was applied to both baseline and training parts of the new intervention.

Like Gledhill et al. (2016), on every training day, a baseline measurement was obtained to establish the category boundary for each participant on that day. It comprised 3 presentations of each of the 15 models in randomised order, totalling 45 trials. The categorical boundary between thin and fat bodies was calculated from the 45 responses as follows. Each presentation that was categorised by a participant as 'thin' scored 1, whereas those categorised as 'fat' scored 0. Gledhill et al. (2016) assumed that the categorical boundary would be captured by a cumulative normal distribution, and that participants did not make errors. In order to match their study as closely as possible, we followed the same (imperfect) logic. According to this, the categorical boundary point could be approximated by summing the total number of thin trials and dividing by the total number of trials. For example, if a participant categorised 25 models as thin, the boundary would be calculated as: $(25/45)*15=8.33$, which, when rounded, would correspond to image 8 of 15 at a BMI of 24.57. For training measurements, the calculation of the categorical boundary followed the same logic. However, in this case participants were presented with 31 trials: bodies 1-2 and 14-15 once only, bodies 3-5 and 11-13 twice, and bodies 6-10 three times, following Gledhill et al. (2016).

Critically, the training phase on each day differed from the baseline measurement in that participants were given feedback on every trial once they had responded. The feedback was displayed in large writing in front of the participant, they were told, e.g. "Correct! That body was fat" or "Incorrect! That body was thin". The nature of the feedback in both the old intervention and new intervention conditions was 'inflationary'. It was designed to shift participants' categorical boundary by two bodies further along the model sequence, towards a higher BMI, than the location of the baseline categorical boundary for the day. For example, suppose a participant's categorical boundary was estimated at image 6/15 (BMI of 21.97) when measured at baseline. During training with inflationary feedback, the boundary would now be set to model 8/15 (BMI of 24.57).

Therefore, during the training phase, if the participant responded to models 7 (BMI of 23.27) or 8 as 'fat' (consistent with their baseline performance), the feedback displayed would be "Incorrect! That body was thin". This way, participants were retrained to judge bodies near their categorical boundary that they had previously judged as fat during the baseline measurement, to be thin. The nature of the feedback for the control condition was not 'inflationary'. Instead, it was consistent with their categorical boundary as measured at baseline and was intended merely to reinforce this. In all cases, once the training sequences had been administered, a post-training categorical boundary was calculated. **Figure 6.2** shows the sequence progression.

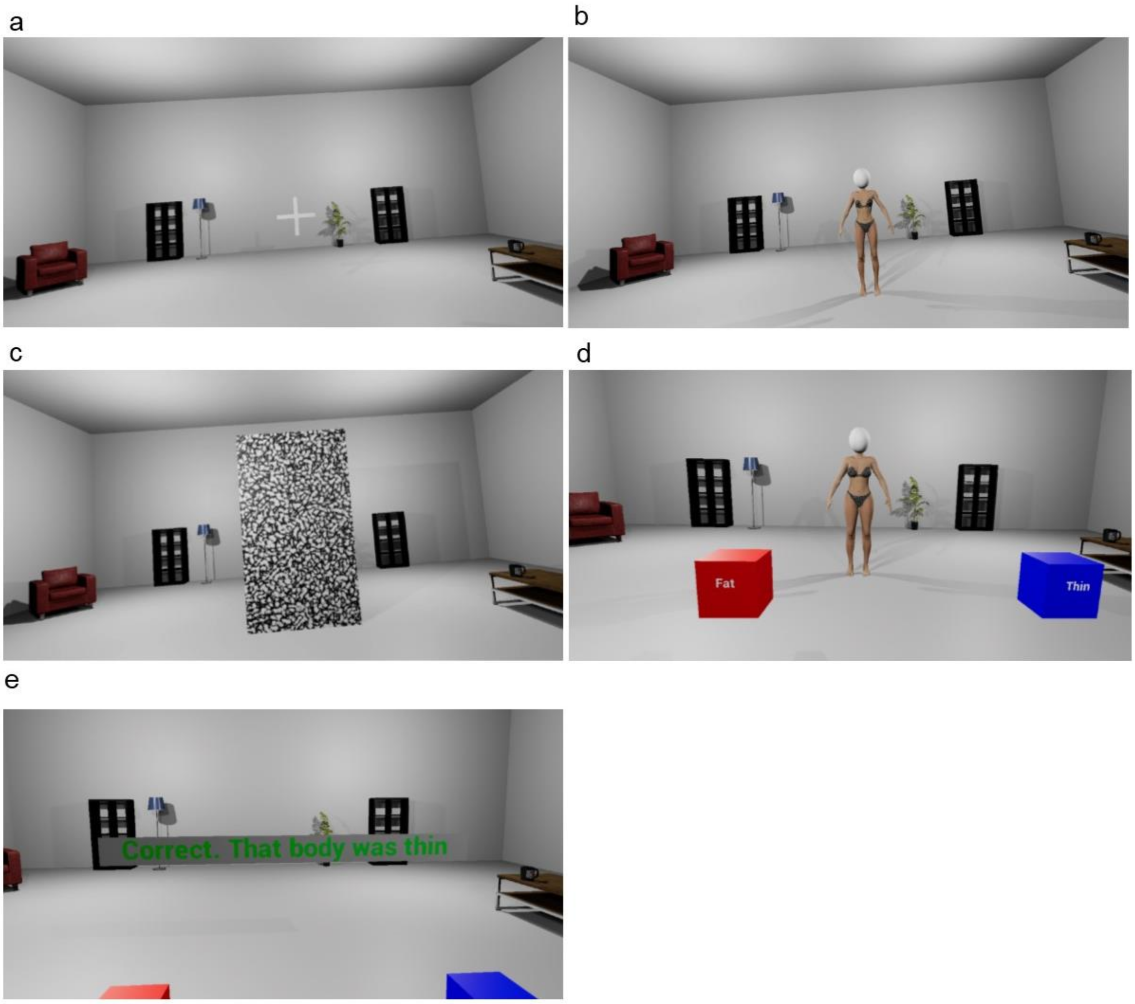


Figure 6.2 *Example training sequence for the old intervention condition: a) the fixation cross, b) model presentation, c) visual noise mask, d) categorisation response boxes, and e) feedback displayed to the participant. Note that no mask was presented in the new intervention condition, and the figure was present in the scene for as long as it took participants to respond.*

6.2.3 Procedure

Consenting participants attended the perceptual training sessions over 4 days. On day 1 participants' weight and height were measured, and the questionnaires were completed, including another measure of the BSQ (Evans & Dolan, 1993), EDE-Q (Fairburn & Beglin, 1994), along with BDI (Beck et al., 1996) and RSE (Rosenberg, 1965). The questionnaires were completed in randomised order. Participants were then instructed on how to wear the Oculus Rift headset, adjust the focus to ensure the stimulus was clearly visible, and shown how to use the Touch Controllers. They then carried out the first baseline and training sequences. On days 2 and 3 participants carried out the perceptual baseline and training sequences only. On day 4, the participants carried out the baseline and training sequences, and then completed the questionnaires: EDE-Q, BSQ, BDI, and RSE. On day 14, at follow up, participants carried out the baseline sequence only and completed the questionnaires: EDE-Q, BSQ, BDI, and RSE.

6.3 Results

Perceptual training

Here we wanted to test: i) whether we could replicate the perceptual training effects reported by Gledhill et al. (2016) when carried out in virtual reality, using the same brief presentation of stimulus and mask; ii) whether we could obtain a perceptual training effect in virtual reality using the new intervention condition with longer stimulus presentation times; iii) whether we could confirm an absence of perceptual training with the control condition.

To do this, we fitted a three-way linear mixed effect model for the perceptual training data using PROC MIXED in SAS v9.4 (SAS Institute, North Carolina, USA). The model included main effects of: (i) timepoint, (i.e. test day: 1, 2, 3, 4 and 14), (ii) intervention (pre-training baseline threshold vs post-training threshold) and (iii) condition (old intervention, control intervention, new intervention), together with all possible two-way and three-way interactions. We ensured that fixed effects were retained only if they contributed a statistically significant reduction in -2 Log Likelihood. The only exceptions were if a non-significant fixed effect compromised part of a significant two- or three-way interaction term, in which case it was retained. In addition, individual variation was permitted at the intercept level for each observer, by including a random effect with an unstructured variance-covariance matrix. All possible pairwise post-hoc comparisons (corrected for multiple comparisons) were computed between the different conditions. To do this, it is mandatory in SAS to include the relevant interaction term to allow the appropriate LSmeans to be calculated; in this case the three-way interaction between timepoint, intervention and condition. The detailed outcome of the statistical modelling is shown in **Table 6.3**.

As **Table 6.3** shows, we found significant main effects of timepoint $F(4,360) = 11.84$, $p < .001$, intervention $F(1,360) = 104.69$, $p < .001$, and condition $F(2,42.5) = 6.25$, $p = .004$. We also found significant two-way interactions between *intervention x condition* $F(2,360) = 8.45$, $p < .001$, and *timepoint x condition* $F(8, 360) = 5$, $p < .001$.

Table 6.3. The results of the three-way model and pairwise comparisons

Model parameters	F-value (DF)	z-value	p-value	Parameter estimate	Parameter 95% C.I.	-2Log likelihood
Empty model						1799.5
Full model						1487.5
Fixed Effects						
Timepoint	11.84 (4, 360)		<.001			
1				-2.60	-3.91 – -1.29	
2				-2.43	-3.74 – -1.12	
3				-1.04	-2.35 – 0.26	
4				-0.26	-1.16 – 0.66	
5				0		
Intervention	104.69 (1,360)		<.001			
Baseline				-2.43	-3.35 – -1.50	
Post-Training				0		
Condition	6.25 (2, 42.5)		.004			
Cont				-2.95	-5.02 – -0.88	
Int_new				1.39	-0.68 – 3.46	
Int_old				0		
Int x cond	8.45 (2, 360)		<.001			
Bline Cont				1.82	0.51 – 3.13	
Bline Int_new				0.69	-0.61 – 2.00	
Bline Int_old				0		
Post-Training Control				0		
Post-Training Int_new				0		
Post-Training Int_old				0		
Cond x Timepoint	5 (8, 360)		<.001			
Cont 1				2.95	1.10 – 4.80	
Cont 2				2.34	0.49 – 4.19	
Cont 3				1.39	-0.46 – 3.24	
Cont 4				0.17	-1.13 – 1.48	
Cont 5				0		
Int_new 1				0.60	-1.24 – 2.46	
Int_new 2				0.69	-1.15 – 2.54	
Int_new 2				-0.08	-1.93 – 1.76	
Int_new 4				-0.34	-1.65 – 0.96	
Int_new 5				0		
Int_old 1				0		
Int_old 2				0		
Int_old 3				0		
Int_old 4				0		
Int_old 5				0		

Table 6.3 continued

Int x Cond x Timepoint	1.66 (9. 360)		.096		
Bline Cont 1				0.17	-1.13 – 1.48
Bline Cont 2				-0.17	-1.48 – 1.13
Bline Cont 3				-0.43	-1.74 – 0.87
Bline Cont 4				0	
Bline Cont 5				0	
Bline Int_new 1				-0.69	-2.00 – 0.61
Bline Int_new 2				-0.69	-2.00 – 0.61
Bline Int_new 3				0.00	-1.30 – 1.30
Bline Int_new 4				0	
Bline Int_new 5				0	
Bline Int_old 1				2.08	0.77 – 3.39
Bline Int_old 2				1.56	0.25 – 2.87
Bline Int_old 3				0.60	-0.70 – 1.91
Bline Int_old 4				0	
Bline Int_old 5				0	
Post-Training Cont 1				0	
Post-Training Cont 2				0	
Post-Training Cont 3				0	
Post-Training Cont 4				0	
Post-Training Cont 5				0	
Post-Training Int_new 1				0	
Post-Training Int_new 2				0	
Post-Training Int_new 3				0	
Post-Training Int_new 4				0	
Post-Training Int_old 1				0	
Post-Training Int_old 2				0	
Post-Training Int_old 3				0	
Post-Training Int_old 4				0	
Random effects					
Subject variance		4.49	<.001	3.31	

Note: Cond = condition, Bline = baseline, int_new = new intervention, int_old = old intervention, cont = control

Figure 6.3a shows plots of the Least Squares Means (LSmeans) for the categorical boundary, derived from our linear mixed effect model, as a function of training day. The data were plotted separately for the different conditions: control intervention (in blue), new intervention (in red) and old intervention (in green), and in each case, split further according to whether the measurement was pre-training (dashed) and post-training (solid lines). **Figure 6.3b** then shows the LSmean difference between baseline and post-training thresholds as a function of training day for the three groups. The error bars represent the 95% C.I.s for pairwise comparisons. **Figure 6.3b** shows a significant effect of training on each training day for the new intervention condition. For the old intervention the first 2 days showed no significant influence of training on the categorical boundary, i.e. no difference between pre- and post-training measurements. However, days 3 and 4 showed significant effect of training. For the control intervention, days 1, 2 and 4, as expected, did not show significant change in the thresholds. Unexpectedly, on day 3 there was a significant difference between pre and post-test thresholds in thin/fat categorisation.

Post-hoc pairwise comparisons between day 1 and day 14 perceptual baselines were calculated to test whether any perceptual training effects persisted over time. For the new intervention a significant increase in BMI of 2.7 BMI units at the categorical boundary was found ($t(336) = -5.72$, $p < .001$) between day 1 ($M = 24.40$) and follow up ($M = 27.10$). In comparison, neither the old intervention ($t(336) = -1.11$, $p = .27$; day 1 $M = 24.49$; follow up $M = 25.01$) nor the control intervention ($t(336) = 1.11$, $p = .27$; day 1 $M = 24.40$; follow up $M = 23.88$), showed significant differences. This suggests that the new training paradigm with longer exposure of the stimuli causes an accumulating shift in participants' categorical boundary towards heavier bodies, and this was retained for at least 2 weeks. Gledhill et al. (2016) found that the shift in categorical boundary persisted at two-week follow up for their 2D training programme. However, while we succeeded in shifting participants' categorical boundaries after 4 days training with the old intervention in VR, this effect did not persist 2 weeks later. In comparison, the new intervention condition in VR, with extended timings, did produce a perceptual training effect that persisted after two weeks.

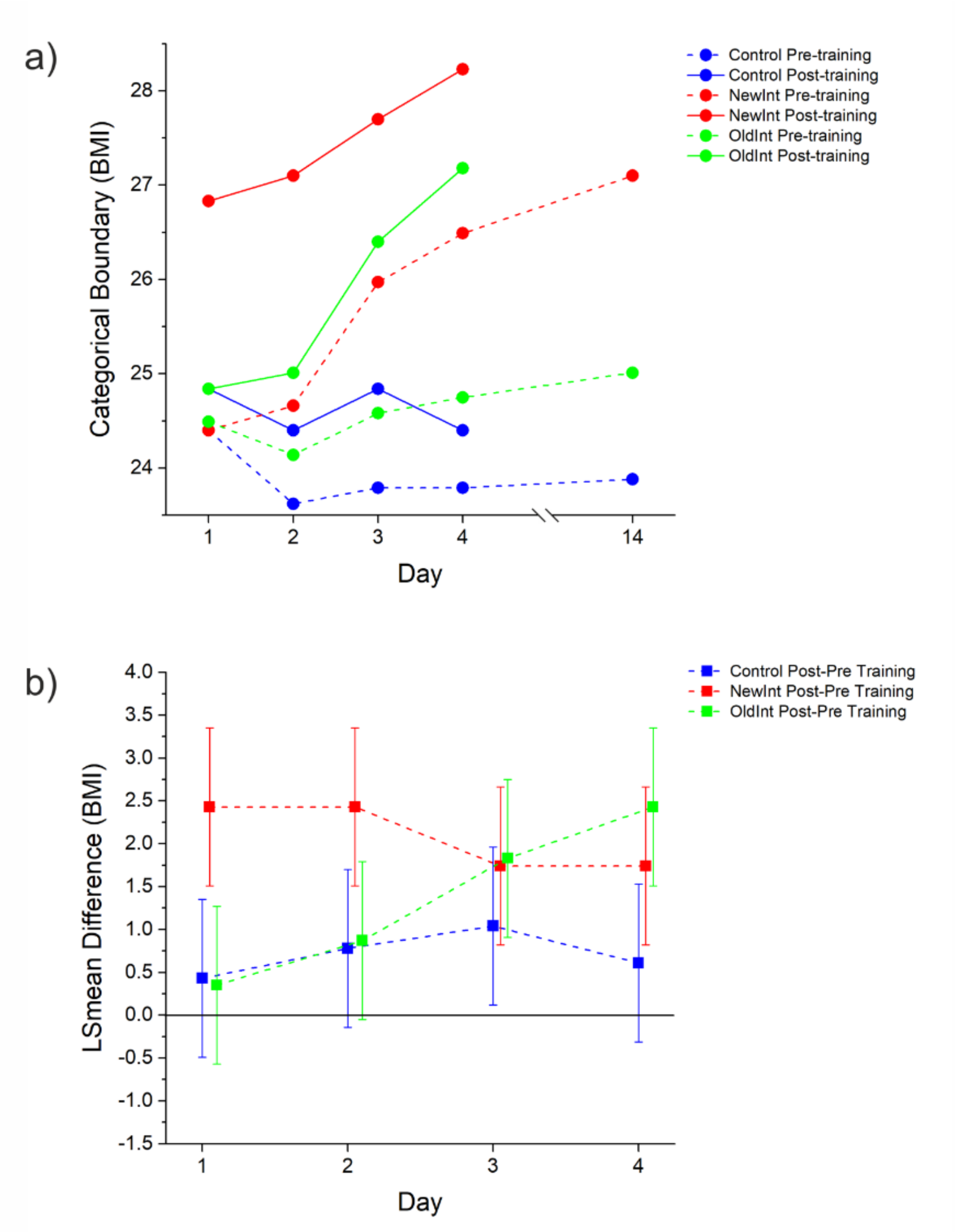


Figure 6.3 *Plot a) shows the mean value of body mass index at the categorical boundary, predicted from the linear mixed effect model as a function of measurement day. Blue circles represent the control group pre-training (dashed lines) and post-training (solid lines). Red circles represent the new intervention condition pre-training (dashed lines) and post-training (solid lines). Green circles represent the old intervention pre-training (dashed lines) and post-training (solid lines). Plot b) shows the predicted differences between pre- and post-training categorical threshold, with 95% C.I., as a function of training day. Confidence intervals that straddle zero are no statistically significant, at p<.05. Blue squares represent the control group, red squares represent the new intervention, and green squares represent the old intervention.*

Psychological measures

For the psychological measures, we used PROC MIXED in SAS v9.4 (SAS Institute, North Carolina, USA) to fit separate linear mixed effect models to participants' BSQ, EDE-Q, EDE-Q _res, EDE-Q _eat, EDE-Q _SC, and EDE-Q_WC measured on day 1, 4 and 14. The psychological measures were transformed into z-scores to facilitate comparison. As before, we ensured that any fixed effect added to a model contributed a statistically significant reduction in -2 Log Likelihood. In addition, individual variation was permitted at the intercept level for each subject by including an 'unstructured' variance-covariance matrix. For the sake of brevity, we focus on the outcomes of the post-hoc comparisons, as reported in **Table 6.4.**

Figure 6.4 shows the LSmeans for the global EDE-Q (plot a) and BSQ scores (plot b) for the control intervention (in black), new intervention (in red) and old intervention (in blue), derived from the linear mixed effect model, plotted as a function of measurement day. They show that EDE-Q scores decreased with time across all conditions. Post-hoc pairwise comparisons between day 1 and day 14 for the BSQ and EDE-Q were calculated to further investigate the reductions in scores. For the new intervention a significant decrease in scores was found for both BSQ: $t(84) = 3.72$, $p = < .001$, and EDE-Q: $t(84) = 3.94$, $p < .001$. Similarly, for the old intervention a significant decrease in scores was found for both BSQ: $t(84) = 4.24$, $p < .001$, and EDE-Q: $t(84) = 3.45$, $p < .001$. In the control we did not find such reductions for either BSQ: $t(84) = 1.03$, $p = .30$ nor EDE-Q: $t(84) = 1.15$, $p = .25$

Figure 6.4 also shows the LSmeans differences in global EDE-Q (plot c) and BSQ (plot d) between control and new intervention (red squares) and control and old intervention (blue squares). The comparison between the new and control interventions showed a significant reduction only for day 14, but not for days 1 and 4. The corresponding comparisons between the old and control interventions for EDE-Q showed no significant difference on any day. The pattern of results for BSQ mirrored almost exactly those for EDE-Q. Only the comparison between the new and control interventions on day 14 showed a significant difference for both BSQ and EDE-Q.

Similar effects were found when comparing the new and old interventions for the BSQ, EDE-Q, and its subscales (see **Table 6.4** for details). In particular, we can see significant differences on the EDE-Q and its subscales: eating, shape and weight concerns; the new intervention shows larger reductions of those scores. With respect to BSQ, the only significant difference occurred at end of training (day 4).

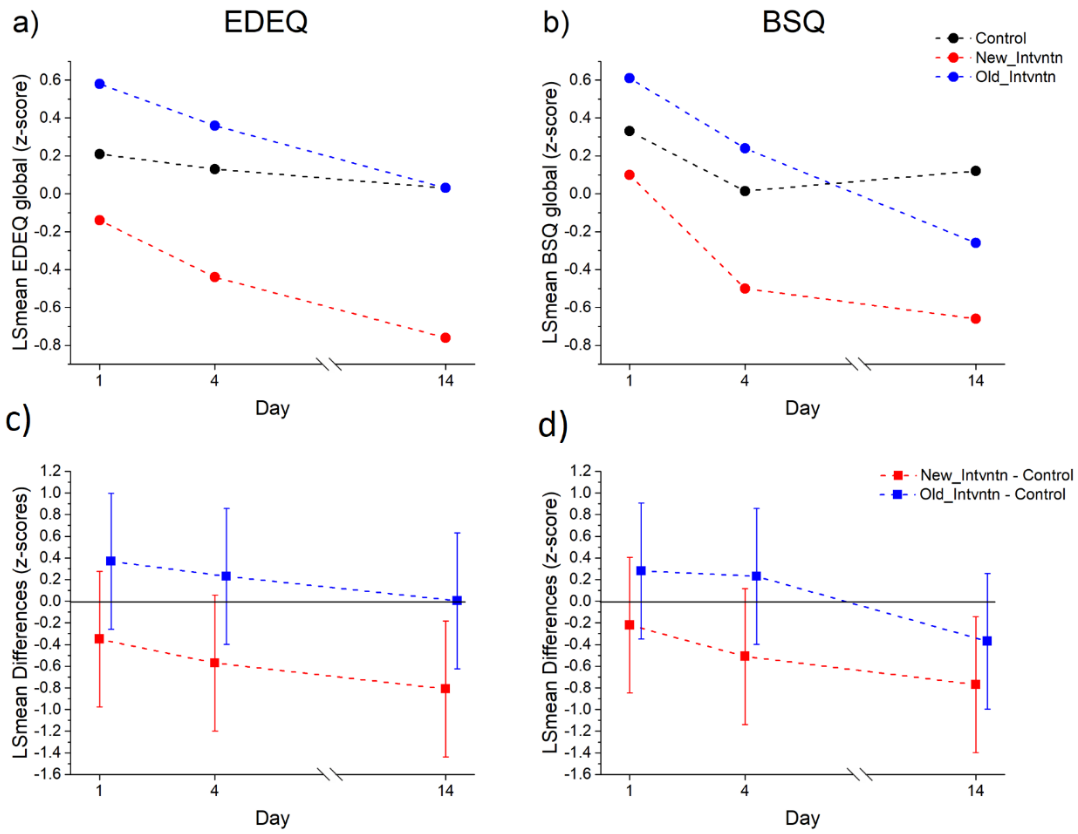


Figure 6.4 *Plot a) shows the predicted global EDE-Q z-scores as a function of measurement day, while b) shows the predicted BSQ z-scores as a function of measurement day; controls in black, new intervention in red and old intervention in blue. Plots c) and d) show the predicted differences in global EDE-Q and BSQ z-scores respectively between the new intervention and controls (in red) and old intervention and controls (in blue) as a function of measurement day, with 95% C.I.s. CIs that straddle the zero are not significant at p < .05.*

Table 6.4. Summary table of the psychological z-scores comparing the new and old training interventions

Measure	Test day	Intervention new	Intervention old	Difference z-scores	95% C.I. z-score	p-value
		Mean (SD)	Mean (SD)			
BSQ	1	0.08 (0.76)	0.57 (0.94)	0.50	-1.14 to 0.12	.116
	4	-0.52 (0.79)	0.20 (0.70)	0.73	-1.37 to -0.10	.023
	14	-0.67 (1.14)	-0.30 (0.93)	0.40	-1.03 to 0.23	.214
EDE-Q global	1	-0.16 (1.12)	0.53 (0.71)	0.71	-1.35 to -0.08	.027
	4	-0.46 (0.9)	0.32 (0.86)	0.79	-1.43 to -0.16	.014
	14	-0.67 (1.14)	-0.01 (0.77)	0.79	-1.43 to -0.15	.015
EDE-Q Restraint	1	0.18 (0.98)	0.08 (0.93)	0.10	-0.61 to 0.81	.773
	4	-0.07 (0.97)	-0.03 (1.02)	0.03	-0.74 to 0.62	.928
	14	-0.20 (1.14)	-0.17 (0.81)	0.02	-0.73 to 0.69	.952
EDE-Q Eating concern	1	-0.12 (1.01)	0.49 (0.97)	0.64	-1.28 to 0.00	.050
	4	-0.38 (0.85)	0.33 (0.85)	0.74	-1.38 to -0.10	.022
	14	-0.57 (0.80	0.09 (0.90)	0.69	-1.33 to -0.05	.033
EDE-Q Shape concern	1	-0.23 (1.11)	0.65 (0.53)	0.90	-1.50 to -0.30	.003
	4	-0.51 (1.02)	0.29 (0.82)	0.82	-1.42 to -0.22	.007
	14	-0.96 (1.18	0.03 (0.81)	1.02	-1.62 to -0.41	.001
EDE-Q Weight concern	1	-0.37 (1.14)	0.56 (0.68)	0.96	-1.54 to -0.38	.001
	4	-0.56 (0.91)	0.47 (0.78)	1.06	-1.64 to -0.48	.000
	14	-0.87 (1.03)	0.01 (0.83)	0.92	-1.49 to -0.34	.002

Note: BSQ = Body Shape Questionnaire, EDE-Q = Eating Disorders Examination Questionnaire with subscales

A key question is whether the reductions we observed in psychological concerns in our sample were clinically meaningful. With respect to the EDE-Q, Bardone-Cone et al. (2010) operationalise recovery in eating-disordered patients as a reduction in all four subscale scores to within 1SD of age-matched community norms. Mond et al. (2006) reported such norm for the 23-27 age group based on a sample of 908 women, those are replicated in **Table 6.5**, along with the mean EDE-Q scores on day 14 for each group. We can conclude that the perceptual training produced reduction in all EDE-Q scores (global and subscales) that were clinically meaningful in the new intervention group, when defined this way. The controls are not expected to fall within the community standards, as we investigated women with heightened body shape concerns

Table 6.5 Shows EDE-Q global score and subscales on day 14, along with 95% CI and community standards

	Control		Intervention new		Intervention old		Community standard		
Measure	*M*	*95% C.I.*	*M*	*95% C.I.*	*M*	*95% C.I.*	*M*	*SD*	*M + 1SD*
EDE-Q global	3.18	2.58 - 3.78	2.30*	1.69 - 2.91	3.08	2.65 - 3.51	1.56	1.26	**2.82**
EDE-Q restraint	2.65*	1.71 - 3.59	2.40*	1.59 - 3.20	2.44*	1.87 - 3.01	1.34	1.39	**2.73**
EDE-Q eating concern	2.28	1.53 - 3.03	1.41*	.87 - 1.96	2.23	1.61 - 2.84	0.81	1.10	**1.91**
EDE-Q shape concern	4.06	3.35 - 4.78	2.89*	2.10 - 3.68	4.09	3.55 - 4.64	2.24	1.61	**3.85**
EDE-Q weight concern	3.73	3.07 - 4.39	2.50*	1.82 - 3.18	3.56	3.01 - 4.11	1.84	1.50	**3.34**

*Indicates score within norm as defined by Mond et al. (2006)

Preliminary comparison of current study and Gledhill et al. (2016)

Here we present a preliminary analysis of the comparison between the 2D intervention by Gledhill et al. (2016) and the VR intervention (with the 'new intervention', i.e. longer exposure of stimuli), at this stage of our investigation, the comparison can only be tentative. Ultimately, the sample size will need to be increased to 20 participants per group to match Gledhill et al. (2016), or increased even further to surpass the small sample size. **Table 6.6** shows the means and standard deviations of the EDE-Q and BSQ in the control and intervention groups in the two studies. **Table 6.7** shows the mean difference on the BSQ and EDE-Q and its subscales between the first day and follow up, for both the control and the new intervention groups in the two studies; negative scores indicate a decrease between day 1 and 14.

Table 6.6 Shows the means and standard deviations of the EDE-Q and BSQ on days 1 and 14, in the control and intervention groups in the two studies

Measure	Test day	Control group				Intervention			
		2D		VR		2D		VR	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
EDE-Q	1	3.67	0.19	3.37	0.22	3.09	0.23	2.93	0.29
	14	3.73	0.20	3.18	0.28	2.64	0.24	2.30	0.28
BSQ	1	69.10	2.61	68.67	3.22	61.20	2.54	64.73	2.54
	14	64.75	2.67	65.93	3.94	60.75	2.66	54.87	3.84

Note: BSQ = Body Shape Questionnaire, EDE-Q = Eating Disorders Examination Questionnaire

Table 6.7 Mean difference between the 2D and VR iterations of the intervention and control conditions on BSQ and EDE-Q (with subscales) scores.

Measure	Control group				Intervention			
	2D		VR		2D		VR	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
BSQ	-4.35	3.08	-2.73	2.55	-0.45	1.51	-9.87	3.65
EDE-Q	0.06	0.15	-0.18	0.15	-0.45	0.13	-0.63	0.25
EDE-Q_res	0.05	0.23	-0.17	0.25	-0.42	0.18	-0.48	0.32
EDE-Q_eat	-0.41	0.29	0.19	0.14	-0.48	0.21	-0.56	0.28
EDE-Q_wc	0.55	0.20	-0.32	0.20	-0.49	0.13	-0.60	0.26
EDE-Q_sc	0.05	0.01	-0.43	0.24	-0.42	0.16	-0.89	0.26

Note: BSQ = Body Shape Questionnaire, EDE-Q = Eating Disorders Examination Questionnaire with subscales: res = restraint, eat = eating concern, wc = weight concern, sc = shape concern

The most important question was to investigate whether there were differential effects of study format (i.e. VR versus 2D) on the day 1 versus day 14 outcomes for BSQ and EDE-Q, when comparing between the control and intervention conditions. To do this, we computed separate linear mixed effect models of these differences in BSQ and EDE-Q scores, using PROC MIXED in SAS v9.4 (SAS Institute, North Carolina, USA). In each model, the main effects were: condition (i.e. control versus intervention), and study format (i.e. 2d versus VR), together with their two-way interactions.

The Type III tests of fixed effects for the BSQ model did not show statistically significant effects of condition (i.e. control vs intervention) $F(1, 70) = 0.36$, $p = .55$ or study format (i.e. 2D vs VR) $F(1,70) = 2.11$, $p = .15$, but there was a significant interaction effect between *condition x study* $F(1,70) = 4.23$, $p = .044$. Post-hoc comparisons between the 2D and VR study formats showed a significant day 1 - day 14 BSQ difference for the intervention conditions: $t(70) = 2.48$, $p = .016$; but not the control $t(70) = -0.43$, $p = .67$.

The Type III tests of fixed effects for the EDE-Q model did not show a statistically significant effect of study format (2D vs VR) $F(1,70) = 1.59$, $p = .21$ but did show an effect of condition (i.e. control vs intervention) $F(1,70) = 8.18$, $p = .006$. There was no significant interaction effect between *condition x study* $F(1,70) = 0.04$, $p = .84$. Post-hoc comparisons between the 2D and VR study formats did not show a significant day 1: day 14 EDE-Q difference for either the intervention conditions: $t(70) = 0.75$, $p = .45$, or the controls $t(70) = 1.03$, $p = .31$.

6.4 Discussion

In the current study, we have attempted to replicate and extend a perceptual training technique used by Gledhill et al. (2016) in immersive virtual reality, to shift body size perception and reduce shape/size concerns in women with heightened body shape concerns. The results have demonstrated that both intervention groups (who received inflationary feedback) shifted the categorical boundary between days 1 and 4. However, this shift in the thin/fat categorisation persisted at follow up (day 14) only for the new intervention, where participants were able to view the stimuli for longer. This highlights that the modified version of the paradigm used by Gledhill et al. (2016) has the potential to be effective in virtual reality, provided that the constraint of brief stimulus presentation is abandoned.

Additionally, for the participants in the new intervention group there was a significant reduction in EDE-Q and BSQ scores between the first day and at the follow up, relative to both the control intervention and the old intervention. This suggests that, in immersive virtual reality only the new training has the potential to improve global body image, i.e. perceptual and attitudinal. However, our conclusions must remain tentative at this stage, as data collection is on-going; we need to recruit more participants to match Gledhill et al. (2016). Furthermore, we should further investigate the 2D version of the training paradigm with no time constraints on the length of stimuli presentation.

The results of Study 1 presented in Chapter 3 suggest a network of associations between different levels of body representation; there appears to be a complex network at play for representing the body. While different nodes in this network may have biases for representing particular information (e.g. perceptual body image, attitudinal body image and body schema), the implication is that there are dynamic connections between all of the network nodes. Therefore, if part of the network infrastructure is adapted, e.g. by modulating perceptual body image, it may follow that other regions in the same network also adapt or follow suit, because of the connections between nodes. If so, such a mechanism may underpin the connection between perceptually retraining participants' categorical boundaries for thin/fat bodies and their subsequent reductions in psychological concerns about body shape, weight and eating.

Another consideration is that learning processes seem to play an important role in the maintenance of disturbed eating and body-related behaviours (Bouton, 2011). Therefore, a change in one domain may establish a cycle, where the change in perception may lead to changes in behaviour that are reciprocated and reinforced. For example, the literature on body exposure suggests that the extent of an individual's negative emotions and cognitions can decrease following a course of mirror confrontation (Vocks et al., 2007). Similarly, weight restoration has been shown to be accompanied by reductions in body dissatisfaction and distortion (Sala et al., 2012).

In general, mechanisms such as these could help explain the effects of perceptual training on the EDE-Q and BSQ scores observed in this study. For example, as described in Chapter 1, the socio-cultural theories suggest associations between appearance-related norms and social comparisons on the development of body dissatisfaction and body image (Festinger, 1954; Polivy & Herman, 2002). When we judge our bodies, we do so within a framework of appearance-related norms (Stice & Shaw, 2002; Tiggemann, 2011). Women high in body dissatisfaction, such as our sample, internalise body ideals more (Smolak & Thompson, 2009) and are more prone to comparing themselves against the standards (Schaefer & Thompson, 2014;

Thompson et al., 1999). When our participants categorised the bodies as thin and fat, it could be argued that they were expressing their internalised norms. We then manipulated these norms experimentally, by confronting the thin/fat categorisation decisions made by our participants with feedback. While completing the task, the participants did not know that the feedback was tailored to them, and as such were led to believe that there is a form of social standard being applied. We can see the effects of our manipulation on the shifting of the perceptual categorical boundary in the new intervention condition. Therefore, we can argue that the norms of thin/fat in that group have effectively changed. As this group is more likely to engage in comparisons, when these ideals were changed for the participants, a comparison against the models may be more favourable. Specifically, the average BMI of the new intervention group was 26.45, their initial average boundary was lower than their own at BMI 24.40; therefore, according to their own categorisation these participants would categorise themselves as ‘fat’, consistent with their high body dissatisfaction scores. However, at follow up, this group’s boundary was equivalent to an average BMI of 27.10, meaning that they may now compare more favourably, i.e. slimmer, than those models that they *now* consider ‘fat’. This could potentially explain the changes in their psychological scores, as downward comparisons have been shown to enhance self-evaluation (Bailey & Ricciadelli, 2010). As levels of satisfaction with one’s own body stem from discrepancies between ideal and actual body size, narrowing or shifting this gap may therefore have led to increased body satisfaction and change related attitudes, as illustrated by the changes in BSQ and EDE-Q scores (Cooper & Taylor, 1988).

Additionally, the cognitive-behavioural model (Cash, 2012) presented in Chapter 1 proposed that the development of body image perception and attitudes are shaped, amongst others, by interpersonal experiences, while Bouton (2011) suggested the importance of learning processes in the development of body image and eating pathology. The feedback we provided to our participants is an example of such experience and/or learning (see **Figure 1.10**). In the new intervention condition, we have demonstrated that feedback has changed the perceptual boundary, i.e. it has changed how shape/size was interpreted, which also led to observed changes in body shape concerns, weight concerns and eating attitudes as measured by the BSQ and EDE-Q.

It is possible that the concerns of women with eating disorders may be harder to modify, as they are more severe than that of non-disordered women; therefore, this new version of the training should be tested in a clinical sample. A large scale, randomised control trial is needed to fully test its feasibility and effectiveness. Although these results should be treated with caution with regards to possible clinical implications until further investigation, they indicate a potential and exciting new approach of treating biases of female body size that are characteristic of anorexia. Such perceptual training can be delivered as an additional treatment for anorexia alongside established treatment, such as cognitive behavioural therapy. While some technical equipment is required to deliver the perceptual training programme in immersive virtual reality, should it be proven to support recovery, the relative low cost of equipment would not be prohibitive. A larger, follow up study should address the convenience, possibly with a mobile virtual reality headset such as Oculus Quest or Samsung Galaxy Gear VR. Furthermore, due to high prevalence of body dissatisfaction in the general population, the programme could also be used with non-clinical samples.

Chapter 7: General discussion

In this chapter we summarise and discuss the main findings of the studies presented in this thesis, along with implications of our findings and suggestions for future research.

7.1 Research aims

The literature review presented in Chapter 1, Introduction provided an overview of the concept of body image comprising two independent modalities: an attitudinal component and a perceptual component, as well as the potential interactions between the two, and their relevance to eating disorder symptomatology and its treatment. The review raised a number of somewhat disparate questions, each of which was investigated empirically in this thesis, as summarised below.

First, prior research has reported disturbances in body representation, including the body schema, in eating disordered populations (Guardia et al., 2012, 2010; Keizer et al., 2017, 2013). These findings suggest that there may be closer functional ties between perceptual body image, attitudinal body image and the body schema than has been appreciated hitherto. Therefore, we investigated how these three levels of representation may normally interact with each other in a sample of non-eating disordered, healthy women.

Secondly, two potential sets of cues have been proposed to drive self-estimates of body size: i) the width of the body estimated from the torso edges (Cornelissen et al., 2009; Smith et al., 2007; Tovée et al., 1999, Tovée & Cornelissen, 2001), and ii) internal visual cues contained within the body outline, such as bony landmarks or rolls of fat that become more visible as body fat changes (Hewig et al., 2008; George et al., 2012; Rilling et al., 2009). Therefore, we ran three experiments to test between these two possibilities.

Thirdly, recent research, particularly by Preston and Ehrsson (2018, 2016, 2014), raises the question whether self-estimates of body size ought to be made from a first- or a third- person point of view. In terms of what is both technically feasible and affordable, we argued that the most appropriate way to address this question would be to use virtual reality (VR) technology. Therefore, we ran preliminary studies to assess whether: i) participants can accurately identify avatars of themselves based on body shape/size information alone, and ii) self-estimates of body size are more or less accurate and precise when made in VR as compared to more conventional 2D methods. Unfortunately, persistent equipment failure prevented us from addressing the final, and most important question with respect to body size estimation and point of view.

Finally, using VR technology, we attempted a replication and extension of an intervention paradigm known to recalibrate participants' perception of body size, leading in turn to reductions in psychological concerns about body image and eating (Gledhill et al., 2016). The central question we wanted to address was whether any clinically useful effects might be more potent in VR than 2D.

7.2 Summary of main research findings

7.2.1 Chapter 3: study 1 – Body schema and body image

In Chapter 3, we investigated how perceptual and attitudinal body image might act to influence the body schema within a typical, healthy population of female adults. One hundred participants estimated the smallest gap between a pair of sliding doors that they could just pass through. We then determined if these estimates sufficed to predict the size of the smallest gap that they could actually pass through, or whether perceptual and attitudinal body image information was required in order to make these predictions. The key findings of Study 1 were:

- Perceptual body image mediated performance on the egocentric motor imagery task, but not for the allocentric control task.

- This pattern of mediation was moderated by attitudinal components of body image. Specifically, mediation occurred only for those individuals with raised body image concerns and low self-esteem.
- Variation in perceptual body image, and gap estimation depended, in turn, on variation in adiposity and muscle mass (i.e. the mesh), and not the lengths of limbs and limb segments (i.e. the rig).

7.2.2 Chapter 4: studies 2, 3 and 4 – Bubbles studies

In chapter 4, using a modified version of the Bubbles paradigm (Gosselin & Schyns, 2001), we investigated the key areas of the body that are used to drive body size judgements. We modified the original bubbles masking paradigm to deliberately emphasise the distinction between central versus edge body information and used a spatial analysis technique to identify stimulus areas that were diagnostic of body size. In addition, we recorded participants' eye-movements when they carried out both masked and unmasked versions of these body size estimation tasks. The key findings from these three studies were:

- Using large bubbles, both accurate and over-estimators used information from the left and right torso edges, to judge body size, and to a lesser extent the central abdomen. A comparison between the two groups showed that accurate estimators made relatively more use of information from the left flank and thigh gap areas, while over-estimators made more use of information from the face and right bust areas.
- Using small bubbles, both accurate and over-estimators primarily made use of the left and right torso edges to judge body size. When comparing between the two groups, accurate size estimators also made use of information about the upper thigh gap, whereas over-estimators made greater use of the right torso edge and, to some extent, the left sub-costal region of the abdomen.

- Eye-movement recordings showed that, whether observers were viewing the masked or unmasked stimuli, fixation patterns were distributed primarily along the centre line of the body. Critically, despite increased dispersion, fixation patterns did not split into separate distributions aligned with the diagnostic edge regions, when observers were presented masked stimuli. This result demonstrated a clear dissociation between fixation patterns and the location of the diagnostic regions used to drive judgements of body size. However, we recommend that this should be tested further.

7.2.3 Chapter 5: studies 5 and 6 – Virtual reality

Preston and Ehrsson (2014, 2016, 2018) have largely been responsible for demonstrating that point of view influences the relationship between perceived body size and ones' attitudes to one's body. Therefore, we carried out a sequence of studies, the ultimate goal of which was to compare body size estimates, and body image attitudes obtained from first- and third-person points of view. To achieve this, we investigated the use of virtual reality in body size estimation tasks. We created personalised avatars of our participants and investigated their ability to detect the presence of their own avatar in a VR scene. We also compared participants' performance on own body size estimation across three different tasks. The key findings of these studies were as follows:

- Most participants could identify that they were present in a VR scene based solely on body shape/size information.
- Participants were most accurate in estimating their body size when performing the task with a personalised avatar in VR.
- Participants over-estimated their size when the task was performed in 2D with standard stimuli, they also under-estimated their size when they performed the task in VR with 3D standard stimuli.

7.2.4 Chapter 6: study 7 – Perceptual training intervention

In Chapter 7 we attempted a replication and extension of an intervention paradigm designed to recalibrate participants' perception of body size (Gledhill et al., 2016). In this study, we asked whether presenting stimuli in immersive virtual reality produced larger effects than the original paradigm, which was delivered using CGI stimuli on a flat panel monitor in 2D. We compared two versions of the VR intervention, one replicating the brief stimulus presentations as used by Gledhill et al. (2016) (referred to as the old intervention) and another in which stimuli were presented for as long as participants took to make their decisions (referred to as new intervention). The key findings of Chapter 7 were:

- Over the course of 4 days, both the old and new interventions, but not the control intervention, shifted individuals' subjective boundaries for categorizing bodies as thin versus fat, towards fatter bodies. However, this perceptual training effect only persisted at two-week follow-up for the new intervention condition.
- Only the difference in EDE-Q and BSQ scores between the control and new intervention was statistically significant at two weeks follow up.
- We carried out a preliminary (but statistically underpowered) comparison of the successful new intervention carried out in VR with the results of Gledhill et al. (2016) carried out in 2D. This showed that the reductions in BSQ scores were larger in the VR version of the training paradigm, with long stimulus exposure, than in the original 2D version. This was not true, however, for EDE–Q.

7.3 Implications

This thesis presents a number of novel findings that have implications for our understanding of body image in adult women. For example, Studies 1 and 7 speak to potentially important inter-connections between different levels of body representation under the broad umbrella of the mind representing the body, and how these appear to be adaptable in nature. In Study 1 we showed that women, who have no concerns about body image and normal self-esteem, can directly predict the size of the smallest gap that they can actually pass through. However, individuals with raised concerns about body image and low self-esteem require additional information about the size and body shape they believed themselves to have, in order to make the same prediction with equivalent accuracy. By comparison, in Study 7 we saw that inducing a change to observers' subjective boundary for thin/fat bodies has a knock-on effect on their attitudes to their own bodies. Both sets of results suggest a degree of malleability which would be hard to explain if deep inter-connections between different aspects of body representation did not pre-exist.

Studies 2-4 provided a surprisingly clear answer as to what regions of the body provide diagnostic information about body size. These findings have the potential to guide therapeutic strategies specifically designed to improve the accuracy of body size judgements in those who mis-estimate body size. This may not only be important for those who over-estimate (such as women with anorexia nervosa), but also for those who under-estimate their size (such as obese individuals), and whose misperception may have serious health consequences (Cornelissen et al., 2016a; Fairburn et al., 2003; Junne et al., 2018; Pike, 1998; Robinson & Kirkham, 2013).

Lastly, Studies 5 and 6 have demonstrated the potential for using immersive virtual reality in self estimates of body size. Frustratingly though, we have yet to obtain the data which would tell us whether VR should be *mandatory* for such measurements, precisely because it allows a first-person point of view. Nevertheless, already our data suggest that studies using anonymised avatars may need to first verify that participants can identify themselves based on body shape/size information alone. For those who can, then our data also suggest that self-estimates of body size may be most accurate and precise when carried out with avatars in VR. However, firmer conclusions await additional control studies.

7.4 Limitations

The need for realistic body stimuli

In Chapter 1, The Introduction, we described how a major limitation of prior investigations of perceptual body image was caused by the choice of stimuli, particularly the video distorting technique (VDT). We suggest there are three possible options for addressing this stimulus problem, all of which have limitations.

The first option is to use images which accurately capture the central statistical tendencies for how body shape changes as a function of BMI, since they are based on relatively large samples (n ~200 - ~500) of body scan data (see **Figure 7.1** for an illustration).

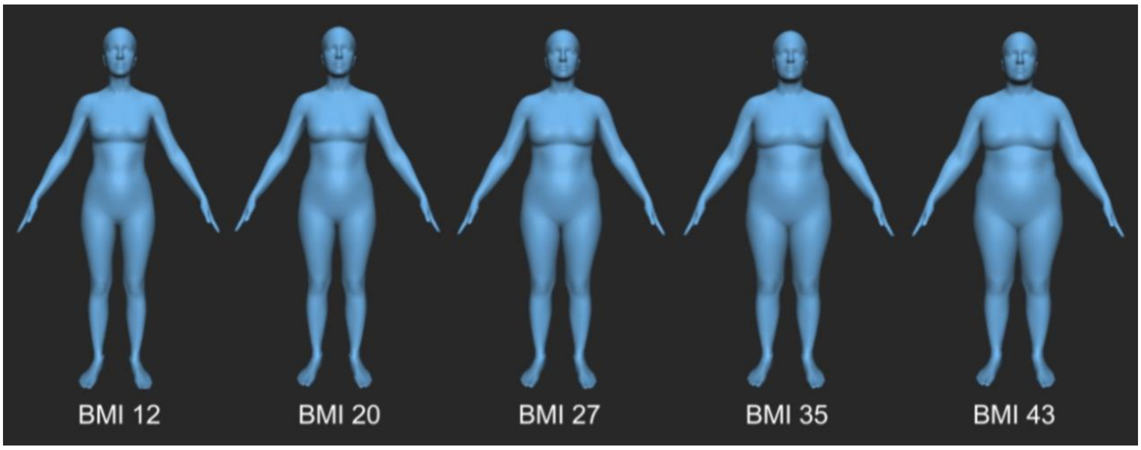


Figure 7.1 *Representations of body shape change in a female (aged 25, 1.65m tall), as a function of BMI, courtesy of Perceiving Systems, MPI, Tubingen. These representations are derived from a statistical model based on a large number of 3D body scans (cf. Hasler et al. 2009).*

However, while statistically accurate, such models inevitably incorporate a great deal of smoothing, and features that might otherwise indicate changing adiposity, e.g. bony landmarks, skin folds and rolls of fat, are not apparent. This may therefore make it more difficult for participants to relate the image they are being shown to their mental representation of their own body. The second option is to modify a standard CGI model to introduce photorealistic changes that reflect BMI dependent changes in body shape, and where these changes can be calibrated for BMI. This is the approach we have taken in this thesis where the method of adjustment and yes-no tasks have been used. While visually compelling, the particular pattern of adiposity dependent shape changes depends on the specifics of that one model and its associated morphs, and these may or may not be close to a true statistical representation. It is as if there is room for some artistic license here. Consequently, this strategy incorporates a fixed bias specific to the individual model. Empirically however, this may be less of a problem that may at first appear. For example, Cornelissen et al. (2016b) demonstrated that Weber's law applies to judgements of BMI in CGI body stimuli. In their study, these authors used two different CGI models each of which had slightly different body shape morphs. Nevertheless, Cornelissen et al. (2016) could find no model dependent differences in the outcomes. The third option is to create individual stimuli, tailored to the shape of each participant as assessed from photographs or 3D body scans. As argued in Chapter 5, individualised avatars solve the problem that not every woman has an underlying body structure which is comparable to an arbitrary standard model. However, we still need to commit to a choice of shape morphs that manipulate adiposity, and a common problem for both the standard CGI models and avatars is that the end points for the morphs are 'fixed'.

7.5 Future research

Inevitably, this thesis may have raised more questions than it has answered. Firstly, we acknowledge that Study 1 was correlational in nature. To fully investigate what we believe to be an interactive network of body representation, we need to test for possible causal connections between representational levels. Therefore, we need to experimentally manipulate perceptual body image, attitudinal body image, and the body schema independently, and assess the impact of these manipulations on real and/or motor imagery tasks. For example, the body schema may be manipulated with the use multisensory conflicts, for example by showing distorted visual feedback during tactile stimulation (Botvinick & Cohen, 1998; Taylor-Clarke, Jacobsen, & Haggard, 2004) and inducing proprioceptive-tactile conflicts such as the Pinocchio Illusion (de Vignemont, Ehrsson, & Haggard, 2005). Therefore, inspired by such research, we will seek ways to manipulate the body schema so as to influence gap estimation, and the direct pathway as illustrated in **Figure 3.1**. Similarly, adaptation tasks (Boothroyd, Tovée, & Pollet, 2012; Winkler & Rhodes, 2010) can be used to manipulate perceptual body image, such that, post-adaptation, participants report the body size they believe themselves to have as smaller or larger than reality. Again, acute, short-term changes to attitudinal body image, particularly dissatisfaction and negative affect, can be induced with body checking (Walker, Murray, Lavender, & Anderson, 2012) and exposure to media thin-ideals (Stice, Spangler, & Agras, 2001).

Secondly, we need to extend the use of the bubble masking technique to studies of individuals who have anorexia nervosa. Cornelissen et al. (2016b) recorded eye movements in women who are recovering from anorexia nervosa and who were asked to judge their body size. They found that such individuals showed gaze patterns in regions of the upper body and face that appeared to be unrelated to their ability to judge body size but were specific to their anorexic status. Therefore, we need to know whether such gaze patterns might also reflect extraction about as yet unknown sources of information. If so, this may open the doors for new approaches for intervention.

In the light of the research by Preston and Ehrsson (2018, 2016, 2014), we need a definitive answer as to whether body size estimation tasks should be performed with body ownership and first-person perspective or not. Therefore, completing the study outlined at the end of Chapter 5 is essential. In addition, we need to understand better the consequences of presenting stimuli in 2D versus 3D/VR on the accuracy and precision of body size judgements. Based on research by Harper and Latto (2001), we should predict size-overestimation of 2D stimuli, compared with orthostereoscopic 3D presentations of the same objects. Therefore, we need to conduct systematic within subject comparisons of body and non-body size estimation tasks, carried out with the same objects/standard bodies/avatars in 2D and 3D/VR. Moreover, with respect to body size estimation, we should also strive to make allocentric versus egocentric comparisons (*cf*. Guardia et al., 2012). It is worth noting that the only study that we are aware of in which body size estimates have been made by the same participants in 2D and 3D, with a life-size stereoscopic display, found under-estimation of own size (Mölbert et al., 2017). However, these authors presented front-facing stimuli to participants in the healthy BMI range (M = 22.07, Min = 19.41, Max = 25.51). Very recently, Cornelissen et al. (2018) have demonstrated that the just noticeable difference (JND) for normal and over-weight stimuli departs from Weber's law *if* they are presented in front view, as compared to side- or three-quarter view. This lack of precision with front view stimuli corresponding to the healthy and over-weight BMI range, may account for the findings of Mölbert et al. (2017).

Finally, to allow a formal comparison with the intervention study carried out by Gledhill et al. (2016), we need to gather 5 more participants per condition for Study 7. In addition, we need to convince ourselves about what causes the apparent advantage of the new intervention in VR, where time constraints on stimulus presentation were removed. Therefore, we also need to carry out a control task using 2D stimulus presentation without time constraints and ask whether this is as effective as 3D/VR presentation without time constraints.

7.6 Conclusions

The findings of the studies presented in this thesis have shed new light on perceptual body image. We have revealed potential connections between perceptual and attitudinal body image and body the schema which were previously unknown. We have found a clear dissociation between where people look when making body size judgements, and the areas that are diagnostic of body size. We have made convincing inroads into how stimuli for body size estimation tasks should best be presented. Finally, we present further evidence from an intervention study to suggest new therapeutic options for body image distortion and its associated psychological concerns.

References

Aardoom, J. J., Dingemans, A. E., Slof Op't Landt, M. C. T., & Van Furth, E. F. (2012). Norms and discriminative validity of the Eating Disorder Examination Questionnaire (EDE-Q). *Eating Behaviours, 13*(4), 305-309. doi: 10.1016/j.eatbeh.2012.09.002

Ackard, D. M., Croll, J. K., & Kearney-Cooke, A. (2002). Dieting frequency among college females: Association with disordered eating, body image and related psychological problems. *Journal of Psychosomatic Research, 52*(3), 129-136. doi: 10.1016/s0022-3999(01)00269-0

Anderluh M. B, Tchanturia, K., Rabe-Hesketh, S., & Treasure, J. (2003). Childhood obsessive-compulsive personality traits in adult women with eating disorders: defining a broader eating disorder phenotype. *American Journal of Psychiatry, 160*, 242-247. doi: 10.1176/appi.ajp.160.2.242

Anderson, S.J., Mullen, K.T., & Hess, R.F. (1991). Human peripheral spatial resolution for achromatic and chromatic stimuli: limits imposed by optical and retinal factors. *Journal of Physiology*, *442*, 47-64. doi: 10.1113/jphysiol.1991.sp018781

Andrew, R., Tiggemann, M., & Clark, L. (2014). Positive body image and young women's health: Implications for sun protection, cancer screening, weight loss and alcohol consumption behaviours. *Journal of Health Psychology, 21*(1), 28-39. doi: 10.1177/1359105314520814

Alexi, J., Cleary, D., Dommisse, K., Palermo, R., Kloth, N., Burr, D., & Bell, J. (2018). Past visual experiences weigh in on body size estimation. *Scientific Reports, 8*(1). doi: 10.1038/s41598-017-18418-3

Allebeck, P., Hallberg, D., & Espmark, S. (1976). Body image – an apparatus for measuring disturbances in estimation of size and shape. *Journal of Psychosomatic Research, 20*(6), 583-584. doi: 10.1016/0022-3999(76)90060-x

Allen, K. L., Byrne, S. M., & McLean, N. J. (2012). The dual-pathway and cognitive-behavioural models of binge eating: prospective evaluation and comparison. *European Child & Adolescent Psychiatry, 21*(1), 51-62. doi: 10.1007/s00787-011-0231-z

Alleva, J., Sheeran, P, Webb, T., Martijn, C., & Miles, E. (2015). A meta-analytic review of stand-alone interventions to improve body image. *PLoS One, 10*(9), e0139177. doi: 10.1371/journal.pone.0139177

Alleva, J., Martijn, C., Van Breukelen, G., Jansen, A., Karos, K. (2015). Expand your Horizon: A programme that improves body image and reduces self-objectification by training women to focus on body functionality. *Body Image, 15*, 81-89. doi: 10.1016/j.bodyim.2015.07.001

Alleva, J. M., Martijn, C., Jansesn, A., & Nederkoorn, C. (2013). Body language: Affecting body satisfaction by describing the body in functionality terms. *Psychology of Women Quarterly, 38*(2), 181-196. doi: 10.1177/0361684313507897.

Alkhadi, H., Brugger, P., Boendermaker, S. H., Crelier, G., Curt, A., Hepp-Reymond, M-C., & Kollias, S. S. (2005). What disconnection tells about motor imagery: evidence from paraplegic patients. *Cerebral Cortex, 15*(2), 131-140.

Almeida, A., Rebelo, F., Noriega, P., & Vilar, E. (2017). Virtual Reality Self Induced Cybersickness: An Exploratory Study. *Advances in Intelligent Systems and Computing, 26–33*. doi:10.1007/978-3-319-60582-1_3

Alsmith, A. J. (2009). Acting on (bodily) experience. *Psyche, 15*(1), 82-99. doi: 10.1016/j.concog.2017.06.006

APA (2013). *Diagnostic and statistical manual of mental disorders: DSM-5.* Arlington, VA; American Psychiatric Association

Arcelus, J., Mitchell, A. J., Wales, J., & Nielsen, S. (2011). Mortality rates in patients with anorexia nervosa and other eating disorders. *Archives of General Psychiatry*, *68*(7), 724-731. doi: 10.1001/archgenpsychiatry.2011.74

Arnau, R. C., Meagher, M. W., Norris, M. P., & Bramson, R. (2001). Psychometric evaluation of the beck depression inventory-II with primary care medical patients. *Health Psychology, 20*(2), 112-119. doi: 10.1037/0278-6133.20.2.112

Askevold, F. (1975). Measuring body image: Preliminary report on a new method. *Psychotherapy and Psychosomatics*, *26*, 71-77. doi: 10.1159/000286913

Avalos, L. C., Tylka, T. L., & Wood-Barcalow, N. (2005). The Body Appreciation Scale: Development and psychometric evaluation. *Body Image*, *2*(3), 285–297. doi: 10.1016/j.bodyim.2005.06.002

Bachner-Melman, R., Zohar, A. H., & Ebstein, R. P. (2006). An examination of cognitive versus behavioral components of recovery from anorexia nervosa*. The Journal of Nervous and Mental Disease, 194*(9), 697–703. doi: 10.1097/01.nmd.0000235795.51683.99

Bailey, S. D. & Ricciardelli, L. A. (2010). Social comparisons, appearance related comments, contingent self-esteem and their relationships with body dissatisfaction and eating disturbance among women. *Eating Behaviors, 11*(2), 107–112. doi: 10.1016/j.eatbeh.2009.12.001

Banfield, S. S. & McCabe, M. P. (2002). An evaluation of the construct of body image. *Adolescence, 37*(146), 373-393.

Bardone-Cone, A. M., Harney, M. B., Maldonado, C. R., Lawson, M. A., Robinson, D. P., Smith, R., & Tosh, A. (2010). Defining recovery from an eating disorder: Conceptualization, validation, and examination of psychosocial functioning and psychiatric comorbidity. *Behaviour Research and Therapy, 48*(3), 194–202. doi:10.1016/j.brat.2009.11.001

Barfield, W. & Hendrix, C. (1995). The effect of update rate on the sense of presence in virtual environments. *Virtual Reality, 1*(1), 3-15. doi: 10.1007/bf02009709

Bassili, J. N. (1979). Emotion recognition: The role of facial movement and the relative importance of upper and lower areas of the face. *Journal of Personality and Social Psychology, 37*(11), 2049–2058. doi:10.1037/0022-3514.37.11.2049

Bearman, S. K., Presnell, K., & Martinez, E. (2006). The skinny on body dissatisfaction: A longitudinal study of adolescent girls and boys. *Journal of Adolescence, 35*, 217-229. Doi: 10.1007/s10964-005-9010-9

Beck, A. T., Steer, R. A., Ball, R., & Ranieri, W. F. (1996). Comparison of Beck Depression Inventories-IA and-II in Psychiatric Outpatients. *Journal of Personality Assessment, 67*(3), 588–597. doi: 10.1207/s15327752jpa6703_13

Beck, A. T., Ward., C. H., Mendelson, M., Mock, J., & Erbaugh, J. (1961). An inventory for measuring depression. *Archives of General Psychiatry, 4*, 561-571. doi: 10.1001/archpsyc.1961.01710120031004

Berlucchi, G. & Aglioti, S. M. (2010). The body in the brain revisited. *Experimental brain Research, 200*(1), 25-35. Doi: 10.1007/s00221-009-1970-7

Berkman, N. D., Lohr, K. N., & Bulik, C. M. (2007). Outcomes of eating disorders: A systematic review of the literature. *International Journal of Eating Disorders, 40*(4), 293–309. doi: 10.1002/eat.20369

Bermudez, J. L. (2005). *The phenomenology of bodily awareness*. In D. Woodruff Smith, A. Thomasson (Eds.) Phenomenology and philosophy of mind (pp. 295-316). Oxford: Claredon Press.

Bell, L. & Rushforth, J. (2008). *Overcoming body image disturbance*. A programme for people with eating disorders. Routledge, London.

Bell, C. Kirkpatrick, S. W., & Rinn, R. C. (1986). Body image of anorexic, obese and normal females. *Journal of Clinical Psychology, 42*(3), 431-439. doi: 10.1002/1097-4679(198605)42:3<431::aid-jclp2270420305>3.0.co;2-i

Blascovich, J., Loomis, J., Beall, A. C., Swinth, R., Hoyt, C. L., & Bailenson, J. N. (2002). Immersive virtual environment technology as a methodological tool for social psychology. *Psychological Inquiry: An International Journal of the Advancement of Psychological Theory, 13*(2), 103-124. doi: 10.1207/s15327965pli1302_01

Blais, C., Roy, C., Fiset, D., Arguin, M., & Gosselin, F. (2012). The eyes are not the window to basic emotions. *Neuropsychologia*, *50*, 2830–2838. doi: 10.1016/j.neuropsychologia.2012.08.010

Blanke, O. (2012). Multisensory brain mechanisms of bodily self-consciousness. *Nature Reviews Neuroscience, 13*(8), 556–571. doi:10.1038/nrn3292

Boothroyd, L. G., Jucker, J.-L., Thornborrow, T., Jamieson, M. A., Burt, D. M., Barton, R. A. Evans, E. H., & Tovée, M. J. (2016). Television exposure predicts body size ideals in rural Nicaragua. *British Journal of Psychology, 107*(4), 752-767. doi: 10.1111/bjop.12184

Boothroyd, L. G., Tovée, M. J., & Pollet, T. V. (2012). Visual Diet versus Associative Learning as Mechanisms of Change in Body Size Preferences. *PLoS ONE, 7*(11), e48691. doi: 10.1371/journal.pone.0048691

Bordo, S. (1993). *Unbearable weight. Feminism, western culture, and the body* (10th Ed.). Berkeley, CA: University of California Press.

Botvinick, M. & Cohen, J. (1998). Rubber hand 'feel' touch that eyes see. *Nature, 391*(6669), 756-756. doi: 10.1038/35784

Brixval, C. S., Rayce, S. L. B., Rasmussen, M., Holstein, B. E., & Due, P. (2011). Overweight, body image and bullying--an epidemiological study of 11- to 15-years olds. *The European Journal of Public Health, 22*(1), 126–130. doi: 10.1093/eurpub/ckr010

Bouton, M. E. (2011). Learning and the persistence of appetite: Extinction and the motivation to eat and overeat. *Physiology and Behavior, 103*, 51–58. doi: 10.1016/j.physbeh.2010.11.025

Brochu, P. M., Gawronski, B., & Esses, V. M. (2011). The integrative prejudice framework and different forms of weight prejudice. *Group Processes & Intergroup Relations, 14*(3), 429-444. doi: 10.1177/1368430210396520

Bruch, H. (1962). Perceptual and Conceptual Disturbances in Anorexia Nervosa. *Psychosomatic Medicine*, 24 (2), 187-194.

Bulik, C. M. (2005). Exploring the gene-environment nexus in eating disorders. *Journal of Psychiatry & Neuroscience*, 30(5), 335-339.

Bulik, C. M., Sullivan, P. F., Tozzi, F., Furberg, H., Lichtenstein, P., & Pedersen, N. L. (2006). Prevalence, heritability, and prospective risk factors for anorexia nervosa. *Archives of General Psychiatry, 63*(3), 305-312. doi: 10.1001/archpsyc.63.3.305

Button, E. J. Sonuga-Barke, E. J. S., Davies, J., & Thompson, M. (1996). A prospective study of self-esteem in the prediction of eating problems in adolescent schoolgirls: Questionnaire findings. *British Journal of Clinical Psychology, 35*(2), 193-203. doi: 10.1111/j.2044-8260.1996.tb01176.x

Cafri, G., Yamamiya, Y., Brannick, M., & Thompson, J. K. (2006). The influence of sociocultural factors on body image: A meta-analysis. *Clinical Psychology: Science and Practice, 12*(4), 421-433. doi: 10.1093/clipsy.bpi053

Caire-Estévez, P., Pons-Vázquez, S., Gallego-Pinazo, R., Sanz-Solana, P., & Pinazo-Durán, M. D. (2011). Restrictive anorexia nervosa: a silent enemy for the eyes and vision. *British Journal of Ophthalmology, 96*(1), 145–145. doi: 10.1136/bjophthalmol-2011-300957

Calder, A. J., Young, A. W., Keane, J., & Dean, M. (2000). Configural information in facial expression perception. *Journal of Experimental Psychology: Human Perception and Performance, 26*, 527–551. doi: 10.1037/0096-1523.26.2.527

Calogero, R. M. (2012). Objectification theory, self-objectification, and body image. In Cash, T. F. (Ed.). *Encyclopedia of Body Image and Human Appearance* (vol. 2). San Diego, Academic Press.

Calogero, R. M., Davis, W. N., & Thompson, K. J. (2005). The role of self-objectification in the experience of women with eating disorders. *Sex Roles, 52*(1-2), 43-50. doi:_10.1007/s11199-005-1192-9

Calogero, R. M. (2004). A test of objectification theory: the effect of the male gaze on appearance concerns in college women. *Psychology of Women Quarterly, 28*(1), 16-21. doi: 10.1111/j.1471-6402.2004.00118.x

Cassin, S., & von Ranson, K. (2005). Personality and eating disorders: A decade in review. *Clinical Psychology Review*, 25(7), 895–916. doi:10.1016/j.cpr.2005.04.012

Carrasco, M. (2011). Visual attention: The past 25 years. *Vision Research*, *51*(13), 1484–1525. doi: 10.1016/j.visres.2011.04.012

Case, L.K., Wilson, R.C., & Ramachandran, V.S. (2012) Diminished size–weight illusion in anorexia nervosa: evidence for visuo-proprioceptive integration deficit. *Experimental Brain Research, 217*(1): 79–87. Doi: 10.1007/s00221-011-2974-7.

Cash, T. F. & Deagle, E. A. (1997). The nature and extent of body-image disturbances in anorexia nervosa and bulimia nervosa: a meta-analysis. *International Journal of Eating Disorders*, *22*(2), 107-126. doi:_10.1002/(sici)1098-108x(199709)22:2<107::aid-eat1>3.0.co;2-j

Cash, T. F. & Pruzinski, T. Body Image. (2002). *A handbook of theory, research, and clinical practice*. New York: Guilford.

Cash, T., Fleming, E., Alindogan, J., Steadman, L., & Whitehead, A. (2002). Beyond Body Image as a Trait: The Development and Validation of the Body Image States Scale. *Eating Disorders, 10*(2), 103–113. doi: 10.1080/10640260290081678

Cash, T. F., Melnyk, S. E., & Hrabosky, J. I. (2004). The assessment of body image investment: An extensive revision of the appearance schemas inventory.

International Journal of Eating Disorders, 35(3), 305–316. doi:-10.1002/eat.10264

Cash, T. F. (2012). Cognitive-behavioral perspectives on body image. In Cash, T. F. (Eds.) *Encyclopaedia of Body Image and Human Appearance* (pp. 334-342). London: Academic Press.

Cash, T. F. (2008). *The body image workbook* (2nd Ed.).New Harbinger Publications: Oakland, CA.

Cash, T. F. (2002). Cognitive-behavioral perspectives on body image. In Cash, T. F. & Pruzinsky, T. (Eds.). *Body images: A handbook of theory, research and clinical practice* (pp. 38-46). New York: Guilford Press.

Cash, T., Fleming, E., Alindogan, J., Steadman, L., & Whitehead, A. (2002). Beyond Body Image as a Trait: The Development and Validation of the Body Image States Scale. *Eating Disorders, 10*(2), 103–113. doi:10.1080/10640260290081678

Cash, T. F. (1995). *What do you see when you look in the mirror? Helping yourself to a positive body image.* New York: Bantam Books.

Cash, T. F. (1994). Body-image attitudes: evaluation, investment, and affect. *Perceptual and Motor Skills, 78*(3), 1168-1170. doi: 10.2466/pms.1994.78.3c.1168

Cash, T. F. & Smolak, L. (2011). *Body image: A handbook of science, practice and prevention*. Guilford Publications, New York.

Casper, R. C., Halmi, K. A., Goldberg, S. C., Eckert, E. D., & Davis, J. M. (1979). Disturbances in body image estimation as related to other characteristics and outcome in anorexia nervosa. *The British Journal of Psychiatry, 134*(1), 60–66. doi: 10.1192/bjp.134.1.60

Castle, D. J. & Philips, K. A. (2002). *Disorders of Body Image*. Wrigthson Biomedical, Petersfield.

Castro, J., Gila, A., Puig, J., Rodriguez, S., & Toro, J. (2004). Predictors of rehospitalization after total weight recovery in adolescents with anorexia nervosa. *International Journal of Eating Disorders, 36*(1), 22–30. doi:10.1002/eat.20009

Cesa, G. L., Manzoni, G. M., Bachetta, M., Castelnuovo, G., Conti, S., Gaggioli, A., Mantovani, F., Molinari, E., Cárdenas-Lopez, G., & Riva, G. (2013). Virtual reality for enhancing the cognitive behavioural treatment of obesity with binge eating disorder: randomized controlled study with one-year follow-up. *Journal of Medical Internet Research, 15*(6), e113.

Channon, S. & De Silva, W. (1985). Psychological correlates of weight gain in patients with anorexia nervosa. *Journal of Psychiatric Research*, *19*, 267-271. doi: 10.1016/B978-0-08-032704-4.50031-0

Chieffi, S., Iavarone, A., La Marra, M., Messina, G., Villano, I., Ranucci, S., Messina, A., Piombino, L., Dalia, C., & Monda, M. (2015). Memory for proprioceptive targets in bulimia nervosa. *Journal of Psychiatry, 18*, 297. Doi: 10.4172/2378-5756.1000297

Cooper, P. J. & Taylor, M. J. (1988). Body image disturbance in bulimia nervosa. *British Journal of Psychiatry, 153*(2), 32-36.

Cooper, P. J., Taylor, M. K., Cooper, Z., & Fairburn, C. G. (1986). The development and validation of the body shape questionnaire. *International Journal of Eating Disorders, 6*(4), 485-494. doi:-10.1002/1098-108x(198707)6:4<485::aid-eat2260060405>3.0.co;2-o

Cornelissen P. L., Cornelissen, K. K., Groves, V., McCarty, K., & Toveé, M. J. (2018). View-dependent accuracy in body mass judgements of female bodies. *Body Image, 24*, 116-123. doi: 10.1016/j.bodyim.2017.12.007

Cornelissen, K. K., McCarty, K., Cornelissen, P. L., & Tovée, M. J. (2017). Body size estimation in women with anorexia nervosa and healthy controls using 3D avatars. *Scientific Reports, 7*(1), 15773. doi: 10.1038/s41598-017-15339-z

Cornelissen, K. (2016). *What does it mean to have distorted body image in anorexia nervosa*? (Doctoral thesis). Retrieved from http://nrl.northumbria.ac.uk/30330/

Cornelissen, K. K., Cornelissen, P. L., Hancock, P. J. B., & Tovée, M. J. (2016a). Fixation patterns, not clinical diagnosis, predict body size over-estimation in eating disordered women and healthy controls. *International Journal of Eating Disorders, 49*, 507-518. doi: 10.1002/eat.22505

Cornelissen, K. K., Gledhill, L. J., Cornelissen, P. L., & Tovée, M. J. (2016b). Visual biases in judging body weight. *British Journal of Health Psychology, 21*(3), 555-569. doi: 10.1111/bjhp.12185

Cornelissen, K. K., Bester, A., Cairns, P., Tovée, M. J., Cornelissen, P.L. (2015). The influence of personal BMI on body size estimations and sensitivity to body size change in anorexia spectrum disorders. *Body Image, 13*, 75-85. doi: 10.1016/j.bodyim.2015.01.001

Cornelissen, P. L., Hancock, P. J. B., Kiviniemi, V., George, H. R., & Tovée, M. J. (2009). Patterns of eye movements when male and female observers judge female attractiveness, body fat and waist-to-hip ratio. *Evolution and Human Behavior, 30*(6), 417–428. doi: 10.1016/j.evolhumbehav.2009.04.003

Cundall, A. & Guo, K. (2015). Women gaze behaviour in assessing female bodies: the effects of clothing, body size, own body composition and body satisfaction. *Psychological Research, 81*(1), 1–12. doi: 10.1007/s00426-015-0726-1

Czernichow, S., Kengne, A.-P., Stamatakis, E., Hamer, M., & Batty, G. D. (2011). Body mass index, waist circumference and waist-hip ratio: which is the better discriminator of cardiovascular disease mortality risk? Evidence from an individual-participant meta-analysis of 82,864 participants from nine cohort studies. *Obesity Reviews*, *12*, 680-687. doi: 10.1111/j.1467-789x.2011.00879.x

Dakanalis, A., Timko, C. A., Carrà, G., Clerici, M., Zanetti, M. A., Riva, G., & Caccialanza, R. (2014). Testing the original and the extended dual-pathway model of lack of control over eating in adolescent girls. A two-year longitudinal study. *Appetite, 82*, 180–193. doi: 10.1016/j.appet.2014.07.022

Datta, R., & DeYoe, E. A. (2009). I know where you are secretly attending! The topography of human visual attention revealed with fMRI. *Vision Research, 49*(10), 1037–1044. doi:10.1016/j.visres.2009.01.014

DeBoer, L. B., Medina, J. L., Davis, M. L., Presnell, K. E., Powers, M. B., & Smits, J. A. J. (2013). Associations between fear of negative evaluation and eating pathology during intervention and in 12-month follow-up. *Cognitive Therapy and Research, 37*(5), 941-952. doi: 10.1007/s10608-013-9547-y

Decety, J., Jeannerod, M. (1995). Mentally simulated movements in virtual reality: does Fitt's law hold in motor imagery? *Behavioural Brain Research, 72*, 127-134. doi: 10.1016/0166-4328(96)00141-6

Delinsky, S. S. & Wilson, G. T. (2006). Mirror exposure for the treatment of body image disturbance. *International Journal of Eating Disorders, 39*(2), 108–116. doi:10.1002/eat.20207

Dijkerman, H. C. & de Haan, E. H. (2007). Somatosensory processes subserving perception and action. *The Behavioural and Brain Sciences, 30*(2), 189-240. doi: 10.1017/s0140525x07001641

Dion, J., Hains, J.,Vachon, P., Plouffe, J., Laberge, L., Perron, M., & Leone, M.(2016). Correlates of body dissatisfaction in children. *The Journal of Pediatrics, 171*, 202–207. doi: 10.1016/j.jpeds.2015.12.045

Dozois, D. J. A., Dobson, K. S., & Ahnberg, J. L. (1998). A psychometric evaluation of the beck depression inventory-II. *Psychological Assessment, 10*(2), 83-89. doi: 10.1037/1040-3590.10.2.83

Drewnowski A, Yee DK (1987) Men and body image: are males satisfied with their body weight? *Psychosomatic Medicine 49*(6), 626–634.

Ehinger, K. A. & Rosenholtz, R. (2016). A general account of peripheral encoding also predicts scene perception performance. *Journal of Vision, 16*(2), 1-19. doi: 10.1167/16.2.13

Ehrsson, H. H., Spence, C., & Passingham, R. E. (2004). That's my hand! Activity in premotor cortex reflects feeling of ownership of a limb. *Science, 305*, 875-877. doi: 10.1126/science.1097011

Ehrsson, H. H., Holmes, N. P., & Passingham, R. E. (2005). Touching a rubber hand: feeling of body ownership is associated with activity in multisensory brain areas. *Journal of Neuroscience, 25,* 10564-10573. doi: 10.1523/jneurosci.0800-05.2005

Ehrsson, H. (2007). The experimental induction of out-of-body experiences. *Science, 317*, 1048. doi:10.1126/science.1142175

Ehrsson, H. H., Wiech, K., Weiskopf, N., Dolan, R. J., & Passingham, R. E. (2007). Threatening a rubber hand that you feel is yours elicits a cortical anxiety response. *Proceedings of the National Academy of Sciences, 104*(23), 9828–9833. doi:10.1073/pnas.0610011104

Engel, M. M. & Keizer, A. (2017). Body representation disturbances in visual perception and affordance perception persist in eating disorder patients after completing treatment. *Scientific Reports, 7*(1). doi:10.1038/s41598-017-16362-w

Eshkevari, E., Rieger, E., Longo, M.R., Haggard, P., & Treasure, J. (2012) Increased plasticity of the bodily self in eating disorders. Psychological Medicine, 42(4): 819–828. doi: 10.1017/S0033291711002091.

Evans, K. K., Horowitz, T. S., Howe, P., Pedersini, R., Reijnen, E., Pinto, Y., Kuzmova, Y., & Wolfe, J. M. (2011). Visual attention. *Wiley Interdisciplinary Reviews: Cognitive Science, 2*(5), 503–514. doi:10.1002/wcs.127

Evans, C. & Dolan, B. (1993). Body Shape Questionnaire: derivation of shortened “alternate forms”. *International Journal of Eating Disorders, 13*, 315-321. doi: 10.1002/1098-108x(199304)13:3<315::aid-eat2260130310>3.0.co;2-3

Fairburn, C. G. & Beglin, S. J. (1994). Assessment of eating disorder psychopathology: interview or self-report questionnaire? International Journal of Eating Disorders, 16, 363-370. doi:-10.1002/1098-108X(199412)16:4<363::AID-EAT2260160405>3.0.CO;2-#

Fairburn, C. G., Cooper, Z., Shafran, R., & Wilson, G. T. (2008). *Eating disorders: a transdiagnostic protocol. Clinical handbook of psychological disorders: A step-by-step treatment manual* (4th Ed.). New York: Guilford Press.

Fairburn, C. G., Cooper, Z., & Shafran, R. (2003). Cognitive behaviour therapy for eating disorders: a “transdiagnostic” theory and treatment. *Behaviour Research and Therapy, 41*(5), 509–528. doi: 10.1016/s0005-7967(02)00088-8

Fairburn, C. G. & Harrison, P. J. (2003). Eating disorders. *The Lancet, 361*, 407-416. doi: 10.1016/s0140-6736(03)12378-1

Fairburn, C. G. & Cooper, Z. (1993). The Eating Disorder Examination (12th Ed.). In: C. G. Fairburn & G. T. Wilson (Eds.). *Binge Eating: Nature, Assessment and Treatment*. (pp. 317-260). New York: Guilford Press.

Farrell, C., Shafran, R., & Lee, M. (2006). Empirically evaluated treatments of body image disturbance: a review. *European Eating Disorders Review, 14*(5), 289-300. doi: 10.1002/erv.693

Farrell, C., Lee, M., & Shafran, R. (2005). Assessment of body size estimation: a review. *European Eating Disorders Review*, *13*(2), 75-88. doi: 10.1002/erv.622

Favaro, A., Santonastaso, P., Manara, R., Bosello, R., Bommarito, G., Tenconi, E., & Di Salle, F. (2012). Disruption of visuospatial and somatosensory functional connectivity in anorexia nervosa. *Biological Psychiatry*, *72(10)*, 864-70. doi: 10.1016/j.biopsych.2012.04.025

Faw, B. (2009). Conflicting intuition may be based on differing abilities: evidence from mental imaging research. *Journal of Consciousness Studies, 16*(4), 45-68.

Felnhofer, A., Kothgassner, O. D., Schmidt, M., Heinzle, A.-K., Beutl, L., Hlavacs, H., & Kryspin-Exner, I. (2015). Is virtual reality emotionally arousing? Investigating five emotion inducing virtual park scenarios. *International Journal of Human-Computer Studies, 82*, 48–56. doi: 10.1016/j.ijhcs.2015.05.004

Ferguson, C. J. (2013). In the eye of the beholder: thin-ideal media affects some, but not most, viewers in meta-analytic review of body dissatisfaction in women and men. *Psychology of Popular Media Culture, 2*(1), 20-37. doi: 10.1037/a0030766

Ferrer-Garcia, M., Gutiérrez-Maldonado, J., & Riva, G. (2013). Virtual Reality Based Treatments in Eating Disorders and Obesity: A Review. *Journal of Contemporary Psychotherapy, 43*(4), 207–221. doi:10.1007/s10879-013-9240-1

Ferrer-García, M. & Gutiérrez-Maldonado, J. (2012). The use of virtual reality in the study, assessment, and treatment of body image in eating disorders and nonclinical samples: A review of the literature. *Body Image, 9*(1), 1–11. doi: 10.1016/j.bodyim.2011.10.001

Ferrer-García, M. & Gutiérrez-Maldonado, J. (2010). Effect of the mood produced by virtual reality exposure on body image disturbances. *Studies in Health Technology and Informatics, 154*, 44-49

Festinger, L. (1954). A theory of social comparison processes. *Human Relations, 7*(2), 117-140. doi: 10.1177/001872675400700202

Fernández-Aranda, F., Dahme, B., & Meermann, R. (1999). Body image in eating disorders and analysis of its relevance: a preliminary study. *Journal of Psychosomatic Research, 47*(5), 419-428. doi: 10.1016/s0022-3999(99)00027-6

Fernández, F., Probst, M., Meermann, R., & Vandereycken, W. (1994). Body size estimation and body dissatisfaction in eating disorder patients and normal controls. *International Journal of Eating Disorders, 16*(3), 307-310. doi: 10.1002/1098-108x(199411)16:3<307::aid-eat2260160313>3.0.co;2-p

Fitzsimmons-Craft, E. E., Bardone-Cone, A. M., Bulik, C. M., Wonderlich, S. A., Crosby, R. D., & Engel, S. G. (2014). *Examining an elaborated sociocultural model of disordered eating among college women: The roles of social comparison and body surveillance. Body Image, 11*(4), 488–500. doi: 10.1016/j.bodyim.2014.07.012

Fredrickson, B. L. & Roberts, T.-A. (1997). Objectification Theory: Toward Understanding Women's Lived Experiences and Mental Health Risks. *Psychology of Women Quarterly, 21*(2), 173–206. doi: 10.1111/j.1471-6402.1997.tb00108.x

Freeman, D., Reeve, S., Robinson, A., Ehlers, A., Clark, D., Spanlang, B., & Slater, M. (2017). Virtual reality in the assessment, understanding, and treatment of mental health disorders. *Psychological Medicine*, *47*(14), 2393–2400. doi: 10.1017/s003329171700040x

Freeman, R. J., Thomas, C. D., Solyom, L., & Hunter, M. A. (1984). A modified video camera for measuring body image distortion: technical description and reliability. *Psychological Medicine, 14*(02), 411. doi: 10.1017/s0033291700003652

Frisén, A., Holmqvist, K., & Oscarsson, D. (2008). 13-year-olds' perception of bullying: definitions, reasons for victimisation and experience of adults' response. *Educational Studies, 34*(2), 105–117. doi: 10.1080/03055690701811149

Friston, K. J., Harrison, L., & Penny, W. (2003). Dynamic causal modelling. *NeuroImage, 19*, 1273-130. doi: 10.1016/SI053-8119(03)00202-7

Fuentes, C. T. Longo, M. R., & Haggard, P. (2013). Body image distortions in healthy adults. *Acta Psychologica*, *144*(2), 344-351. doi: 10.1016/j.actpsy.2013.06.012

Fulkerson, J. A., Sherwood, N., Perry, C. L., Neumark-Sztainer, D., & Story, M. (2004). Depressive symptoms and adolescent eating and health behaviours: a multifaceted view in a population based sample. *Preventive Medicine, 38*(6), 865-875. doi: 10.1016/j.ypmed.2003.12.028

Gallagher, S. (2005). *How the body shapes the mind*. New York: Oxford University Press.

Gao, Q., Duan, X., & Chen, H. (2011). Evaluation of effective connectivity of motor areas during motor imagery and execution using conditional granger causality. *Neuroimage, 54,* 1280-1288. Doi: 10.1016/j.neuroimage.2010.08.071

Gardner, R. M. & Brown, D. L. (2014). Body size estimation in anorexia nervosa: a brief review of findings from 2003 through 2013. *Psychiatry Research, 219*(3), 407-410. doi: 10.1016/j.psychres.2014.06.029

Gardner, R. M. (2011). Perceptual Measures of Body Image for Adolescents and Adults. In Cash, T. F & Smolak, L. (Eds.). *Body Image. A handbook of science, practice and prevention* (2nd Ed.). The Guilford Press: New York.

Gardner, R. M. & Brown, D. L. (2010). Body image assessment: A review of figural drawing scales. *Personality and Individual differences, 48*(2), 107–111. doi: 10.1016/j.paid.2009.08.017

Gardner, R. M. & Boice, R. (2004). A computer program for measuring body size distortion and body dissatisfaction. *Behavior Research Methods, Instruments, & Computers, 36*(1), 89-95. doi: 10.3758/bf03195553

Gardner, R. M., Friedman, B. N., & Jackson, N. A. (1998). Methodological Concerns When Using Silhouettes to Measure Body Image. *Perceptual and Motor Skills, 86*(2), 387–395. doi: 10.2466/pms.1998.86.2.387

Gardner, R.M., & Moncrieff, C. (1988). Body image distortion in anorexics as a non-sensory phenomenon: A signal detection approach. *Journal of Clinical Psychology, 44*(2), 101–107. doi: 10.1002/1097-4679(198803)44:2<101::aid-jclp2270440203>3.0.co;2-u

Gardner, R. M. & Bokenkamp, E. D. (1996). The role of sensory and nonsensory factors in body size estimations of eating disorder subjects. *Journal of Clinical Psychology, 52*(1), 3-15. doi: 10.1002/(sici)1097-4679(199601)52:1<3::aid-jclp1>3.0.co;2-x

Gardner, R. M., Jones, L. C., & Bokenkamp, E.D. (1995). Comparison of three psychophysical techniques for estimating body-size perception. *Perceptual and Motor Skills, 80*(3_Suppl), 1379-1390. doi: 10.2466/pms.1995.80.3c.1379

Garner, D. M., Garfinkel, P. E., & Bonato, D. P. (1987). Body image measurement in eating disorders. *Research Paradigms in Psychosomatic Medicine, 17*, 119-133. doi: 10.1159/000414010

Garner, D. M. & Bemis, K. M. (1982). A cognitive-behavioral approach to anorexia nervosa. *Cognitive Therapy and Research, 6*(2), 123-150. doi: 10.1007/bf01183887

Garner, D. M. & Garfinkel, P. E. (1982). Body image in anorexia nervosa: measurement, theory and clinical implications. *The International Journal of Psychiatry in Medicine, 11*(3), 263-284. Doi: 10.2190.r55q-2u6t-lam7-rqr7

Garner, D. M., Garfinkel, P. E., Stancer, H. C., Moldofsky, H. (1976). Body image disturbances in anorexia nervosa and obesity. *Psychosomatic Medicine, 38*(5), 327-336. doi: 10.1097/00006842-197609000-00005

Gaudio, S., Brooks, S. J., & Riva, G. (2014). Nonvisual multisensory impairment of body perception in anorexia nervosa: A systematic review of neuropsychological studies. *PlosONE, 9*(10), e110087. doi: 10.1371/journal.pone.0110087

George, H. R., Cornelissen, P. L., Hancock, P. J. B., Kiviniemi, V. V., & Tovée, M. J. (2011). Differences in eye-movement patterns between anorexic and control observers when judging body size and attractiveness. *British Journal of Psychology, 102*(3), 340–354. doi:10.1348/000712610x524291

Gegenfurtner, K. R. (2016). The Interaction Between Vision and Eye Movements. *Perception, 45*(12), 1333–1357. doi: 10.1177/0301006616657097

Gervais, S. J., Holland, A. M., & Dodd, M. D. (2013). My Eyes Are Up Here: The Nature of the Objectifying Gaze Toward Women. *Sex Roles, 69*(11-12), 557–570. doi: 10.1007/s11199-013-0316-x

Gescheider, G. A. (1997). *Psychophysics. The Essentials*. 3rd ed. London: Lawrence Erlbaum Associates Publishers.

Giavarina, D. (2015). Understanding Bland Altman analysis. *Biochemia Medica*, *25*(2), 141-151. doi: 10.11613/bm.2015.015

Gibbons, F. X. & Gerrard, M. (1989). Effects of upward and downward social comparison on mood states. *Journal of Social and Clinical Psychology, 8*(1), 14-31. doi: 10.1521/jscp.1989.8.1.14

Gila, A., Castro, J., Cesena, J., & Toro, J. (2005). Anorexia nervosa in male adolescents: Body image, eating attitudes and psychological traits. *Journal of Adolescent Health, 36*(3), 221–226. doi: 10.1016/j.jadohealth.2004.02.039

Gila, A., Castro, J., Toro, J., & Salamero, M. (1998). Subjective body-image dimensions in normal and anorexic adolescents. *British Journal of Medical Psychology, 71*(2), 175–184. doi: 10.1111/j.2044-8341.1998.tb01378.x

Gilbert, J. M., Weiss, J. S., Sattler, A. L., & Koch, J. M. (1990). Ocular Manifestations and Impression Cytology of Anorexia Nervosa. *Ophthalmology, 97*(8), 1001–1007. doi: 10.1016/s0161-6420(90)32473-9

Gledhill, L. J., Cornelissen, K. K., Cornelissen, P. L., Penton-Voak, I. S., Munafò, M. R., & Tovée, M. J. (2016). An interactive training programme to treat body image disturbance. *British Journal of Health Psychology, 22*(1), 60–76. doi: 10.1111/bjhp.12217

Gleghorn, A. A., Penner, L. A., Powers, P. S., & Schulman, R. (1987). The psychometric properties of several measures of body image. *Journal of Psychopathology and Behavioral Assessment, 9*(2), 203–218. doi: 10.1007/bf00960575

Glucksman, M. L. & Hirsch, J. (1969). The response of obese patients to weight reduction: III. The perception of body size. *Psychosomatic Medicine, 31*(1), 1–7. doi: 10.1097/00006842-196901000-00001

Goodwin, G. M., McCloskey, D. I., & Matthews, P. B. (1972). Proprioceptive illusions induced by muscle vibration: contribution by muscle spindles to perception? *Science*, 175(4028), 1382–1384. doi: 10.1126/science.175.4028.1382

Gorini, A., Capideville, C. S., De Leo, G., Mantovani, F., & Riva, G. (2011). The role of immersion and narrative in mediated presence: The virtual hospital experience. *Cyberpsychology, Behavior, and Social Networking, 14*, 99–105. doi: 10.1089/cyber. 2010.0100

Gosselin, F. & Schyns, P. G. (2004). No troubles with bubbles: a reply to Murray and Gold. *Vision Research, 44*(5), 471–477. doi:10.1016/j.visres.2003.10.007

Gosselin, F. & Schyns, P. (2001). Bubbles: a technique to reveal the use of information in recognition tasks. *Vision Research, 41*(17), 2261–2271. doi: 10.1016/s0042-6989(01)00097-9

Grabe, S., Hyde, J. S., & Ward, L. M. (2008). The role of the media in body image concerns among women. A meta-analysis of experimental and correlational studies. *Psychological Bulletin, 134*(3), 460–476. doi: 10.1037/0033-2909.134.3.460

Green, D. M. & Swets, J. A. (1966). *Signal Detection theory and psychophysics*. New York: Wiley.

Griffiths, C. (2015). *The role of psychological inflexibility in the tripartite influence model for women: a single body image inflexibility pathway to disordered eating behaviours* (Doctoral dissertation). Retrieved from: University of the West of England http://eprints.uwe.ac.uk/27739/

Griffiths, R. A., Beumont, P. J. V., Giannakopoulos, E., Russell, J., Schotte, D., Thornton, C., Touyz, S. W., Varano, P. (1999). Measuring self-esteem in dieting disordered patients: the validity of the Rosenberg and Coopersmith contrasted. *International Journal of Eating Disorders*, *25*(2), 227-231. doi:-10.1002/(sici)1098-108x(199903)25:2<227::aid-eat13>3.0.co;2-4

Groesz, L. M., Levine, M. P., & Murnen, S. K. (2001). The effect of experimental presentation of thin media images on body satisfaction: a meta-analytic review. *International Journal of Eating Disorders, 31*(1), 1-16. doi: 10.1002/eat.10005

Guardia, D., Carey, A., Cottencin, O., Thomas, P., & Luyat, M. (2013). Disruption of spatial task performance in anorexia nervosa. *PLoS One, 8*(1), e54928. doi: 10.1371/journal.pone.0054928.

Guardia, D., Conversy, L., Jardri, R., Lafargue, G., Thomas, P., et al. (2012). Imagining one's own and someone else's body actions: Dissociation in Anorexia Nervosa. *PLoS ONE*, *7*(8): e43241. doi: 10.1371/journal.pone.0043241.

Guardia, D., Lafargue, G., Thomas, P., Dodin, V., Cottencin, P., et al. (2010). Anticipation of body-scaled action is modified in anorexia nervosa. *Neuropsychologia, 48*, 3961-3966. doi: 10.1016/j.neuropsychologia.2010.09.004.

Gutiérrez-Maldonado, J., Ferrer-García, M., Dakanalis, A., & Riva, G. (2018). *Virtual Reality*. Oxford Handbooks Online. doi: 10.1093/oxfordhb/9780190620998.013.26

Gutiérrez-Maldonado, J., Pla-Sanjuanelo, J., & Ferrer-García, M. (2016). Cue-exposure software for the treatment of bulimia nervosa and binge eating disorder. *Psicothema, 28*(4), 363-369.

Haggard, P. & Wolpert, D. M. (2005). Disorders of body scheme. In Freund, H. J., Jeannerod, M., Hallett, M., Leiguarda, R. (Eds.). *Higher-order motor disorders*. New York: Oxford University Press.

Hagman, J., Gardner, R. M., Brown, D. L., Gralla, J., Fier, J. M., & Frank, G. K. W. (2015). Body size overestimation and its association with body mass index, body dissatisfaction, and drive for thinness in anorexia nervosa. *Eating and Weight Disorders, 20*(4), 449-455. doi: 10.1007/s40519-015-0193-0

Haines, J. & Neumark-Sztainer, D. (2006). Prevention of obesity and eating disorders. A consideration of shared risks factors. *Health Education Research, 21*(6), 770-782. doi: 10.1093/her/cyl094

Hamilton, K. & Waller, G. (1993). Media influences on body size estimation in anorexia and bulimia: an experimental study. *The British Journal of Psychiatry, 162*(6), 837-840. doi: 10.1192/bjp.162.6.837337

Hanakawa, T., Immisch, I., Toma, K., Dimyan, M. A., van Gelderen, P., & Hallerr, M. (2003). Function properties of brain areas associated with motor execution and imager. *Journal of Neurophysiology, 89*, 989-1002. doi: 10.1152/jn.00132.2002

Hasler, N., Stoll, C., Sunkel, M., Rosenhahn, B., & Seidel, H.-P. (2009). A statistical model of human pose and body shape. *Computer Graphics Forum, 28*(2), 337-346. doi: 10.1111/j.1467-8659.2009.01373.x

Harper, B. & Tiggemann, M. (2007). The effect of thin ideal media images on women's self-objectification, mood and body image. *Sex Roles, 58*(9-10), 649-657. doi: 10.1007/s11199-007-9379-x

Harper, B. & Latto, R. (2001). Cyclopean vision, size estimation, and presence in orthostereoscopic images. *Presence, 10*(3), 312-330. doi: 10.1162/105474601300343630

Hay, P.J., Claudino, A. M., Touyz, S., & Elbaky, G. (2015). Individual psychological therapy in the outpatient treatment of adults with anorexia nervosa (review).

Cochrane Database of Systematic Reviews, 7, 1-97. doi: 10.1002/14651858.cd.003909.pub2

Hayes, A. F. (2015). An Index and Test of Linear Moderated Mediation. *Multivariate Behavioral Research, 50*(1), 1-22. doi: 10.1080/00273171.2014.962683

Head, H. (1920). *Studies in neurology.* Hodder Stoughton, London.

Head, H. & Holmes, H. G. (1911–1912). Sensory disturbances from cerebral lesions. *Brain*, *34*, 102–254. doi: 10.1016/S0140-6736(01)64640-3

Health Survey for England (2014). National Centre for Social Research and University College London. Department of Epidemiology and Public Health. UK Data Archive, Colchester, Essex, UK.

Health Survey for England (2008). National Centre for Social Research and University College London. Department of Epidemiology and Public Health. UK Data Archive, Colchester, Essex, UK.

Heilbrun, A. B. & Friedberg, L. (1990). Distorted body image in normal college women: Possible implications for the development of anorexia nervosa. Psychodynamics and Psychopathology, 46(4), 398-401. *Journal of the American Academy of Child and Adolescent Psychiatry, 46*(4), 389-401. doi:10.1002/1097-4679(199007)46:4<398::aid-jclp2270460404>3.0.co;2-5

Herzog, D. B., Dorer, D. J., Keel, P. K., Selwyn, S. E., Ekeblad, E. R., Flores, A. T., Greenwood, D. N., Burwell, R. A., & Keller, M. D. (1999). Recovery and relapse in anorexia nervosa and bulimia nervosa: A 7.5-year follow-up study. *Journal of the American Academy of Childhood and Adolescent Psychiatry, 38*(7), 829-837. doi: 10.1097/00004583-199907000-00012

Hesslow, G. (2012). The current status of the simulation theory of cognition. *Brain Research, 1428*, 71-79. Doi: 10.1016/j.brainres.2011006026

Hewig, J., Cooper, S., Trippe, R. H., Hecht, H., Straube, T., & Miltner, W. H. R. (2008). Drive for Thinness and Attention Toward Specific Body Parts in a Nonclinical Sample. *Psychosomatic Medicine, 70*(6), 729–736. doi: 10.1097/psy.0b013e31817e41d3

Higham, P. A. & Arnold, M. M. (2007). Beyond reliability and validity: the role of metacognition in psychological testing. In DeGregorio, A. A. (Ed.) *New Developments in Psychological Testing* (pp. 139-162). Hauppauge, NY: Nova Science.

Hillard, E. E., Gondoli, D. M., Corning, A. F., & Morrissey, R. A. (2016). In in together: mother talk of weight concerns moderates negative outcomes of encouragement to lose weight on daughter body dissatisfaction and disordered eating. *Body Image, 16*, 21-27. doi: 10.1016/j.bodyim.2015.09.004

Hoek, H.W. & van Hoeken, D. (2003). Review of the prevalence and incidence of Eating Disorders. *International Journal of Eating Disorders*, *34*(4), 383-396. doi: 10.1002/eat.10222

Hoffmeister, K., Teige-Mocigemba, S., Blechert, J., Klauer, K. C., Tuschen-Caffier, B. (2010). Is implicit self-esteem linked to shape and weight concerns in restrained and unrestrained eaters? *Journal of Behaviour Therapy and Experimental Psychiatry, 41*(1), 31-38. doi: 10.1016/j.jbtep.2009.08.009

Hofmann, W., Gawronski, B., Gschwendner, T., Le, H., & Schmitt, M. (2005). A Meta-Analysis on the Correlation Between the Implicit Association Test and Explicit Self-Report Measures. *Personality and Social Psychology Bulletin, 31*(10), 1369–1385. doi: 10.1177/0146167205275613

Hsu, G. L. K. (1982). Is there a disturbance in body image in anorexia nervosa? *The Journal of Nervous and Mental Disease, 170*(5), 305-307. doi: 10.1097/00005053-198205000-00009

Hudson, J. I., Hiripi, E., Pope Jr, H. G., & Kessler, R. C. (2007). The prevalence and correlates of eating disorders in the national comorbidity survey replication. *Biological Psychiatry, 61*(3), 348-358. doi: 10.1016/j.biopsych.2006.03.040

Humphreys, K., Minshew, N., Leonard, G. L., & Behrmann, M. (2007). A fine-grained analysis of facial expression processing in high-functioning adults with autism. *Neuropsychologia, 45*(4), 685–695. doi:10.1016/j.neuropsychologia.2006.08.003

Huxley, C. J., Halliwell, E., & Clarke, V. (2014). An examination of the tripartite influence model of body image. *Psychology of Women Quarterly, 39*(3), 337-348. doi:10.1177/0361684314554917

Hüttermann, S., Memmert, D., Simons, D. J., & Bock, O. (2013). Fixation Strategy Influences the Ability to Focus Attention on Two Spatially Separate Objects. *PLoS ONE, 8*(6), e65673. doi: 10.1371/journal.pone.0065673

Jack, R. E., Caldara, R., & Schyns, P. G. (2012). Internal representations reveal cultural diversity in expectations of facial expressions of emotion. *Journal of Experimental Psychology: General*, *141*, 19–25. doi: 10.1037/a0023463

Jensen, A., Nedekoorn, C., & Mulkens, S. (2005). Selective visual attention for ugly and beautiful body parts in eating disorders. *Behaviour Research and Therapy, 43*(2), 183-196. doi: 10.1016/j.brat.2004.01.003

Johnson, F. & Wardle, J. (2005). Dietary restraint, body dissatisfaction and psychological distress: a prospective analysis. *Journal of Abnormal Psychology, 114*(1), 119-125. doi: 10.1037/0021-843x.114.1.119

Johns, C., Nunez, D., Daya, M., Sellars, D, Casanueva, J., & Blake, E. (2000). The Interaction Between individuals' immersive tendencies and the sensation of presence in a virtual environment (pp. 66-74). In Mulder, J., van Liere, R. (Eds). *Virtual Environments*. Vienna: Springer

Jones, D. C., Vigfusdottir, T. H., & Lee, Y. (2004). Body image and the appearance culture among adolescent girls and boys: an examination of friend conversations, peer criticism, appearance magazines and internalization of appearance ideals. *Journal of Adolescent Research, 19*, 323-339. doi: 10.1177/0743558403258847

Junne, F., Wild, B., Resmark, G., Giel, K.E., Teufel, M., & Martus, et al. (2018). The importance of body image disturbances for the outcome of outpatient psychotherapy in patients with anorexia nervosa: Results of the ANTOP-study. *European Eating Disorders Review*, *1–10.* doi: 10.1002/erv.2623

Kammers, M. P. M., de Vignemont, F., Verhagen, L., & Dijkerman, H. C. (2009). The rubber hand illusion in action. *Neuropsychologia, 47*(1), 204-211. doi: 10.1016/j.neuropsychologia.2008.07.028

Kammers, M. P. M., van der Ham, I. J., & Dijkerman, H. C. (2006). Dissociating body representations in healthy individuals: differential effects of a kinaesthetic illusion on perception and acting. *Neuropsychologia, 44*(2), 2430-2436. doi: 10.1016/j.neuropsychologica.2006.04.009

Kammers, M. P. M., Kootker, J. A., Hogendoorn, H., & Dijkerman, H. C. (2010). How many motoric body representations can we grasp? *Experimental Brain Research, 202*, 203-212. doi: 10.1007/s00221-009-2124-7

Kaye, W., Strober, M., & Rodes, L. (2002). Body image disturbance and other core symptoms in anorexia and bulimia nervosa. In Castle, D. J. & Phillips, K. A. (Eds), *Disorders of Body Image*. Petersfield: Wrightson Biomedcial Publishing, Ltd.

Keizer, A., Smeets, M.A.M., Postma, A., van Elburg, A., & Dijkerman, H.C. (2014). Does the experience of ownership over a rubber hand change body size perception in anorexia nervosa patients? *Neuropsychologia, 62*, 26-37. doi: 10.1016/j.neuropsychologia.2014.07.003.

Keizer, A., Smeets, M. A. M., Dijkerman, H. C., Uzunbajakau, S. A., van Elburg, A., & Postma, A. (2013). Too fat to fit through the door: first evidence for disturbed body-scaled action in anorexia nervosa during locomotion. *Plos One, 8*(5), e64602. doi: 10.1371/journal.pone.0064602

Keizer, A., Smeets, M.A.M., Dijkerman, H.C., van Elburg, A., & Postma, A. (2012). Aberrant somatosensory perception in Anorexia Nervosa. Psychiatry Research, 200(2), 530–537. doi: 10.1016/j.psychres.2012.05.001

Keizer, A., Smeets, M. A. M., Dijkerman, H. C., van den Hout, M., Klugist, I., van Elberg, A., & Postma, A. (2011). Tactile body image disturbance in anorexia nervosa. *Psychiatry Research, 190*(1), 115-120. Doi: 10.1016/j.psychres.2011.04.031

Keel, P. K., Dorer, D. J., Franko, D. L., Jackson, S. C., Herzog, D. B. (2005). Postremission predictors of relapse in women with eating disorders. *The American Journal of Psychiatry, 162*(12), 2263-2268. doi: 10.1176/appi.ajp.162.12.2263

Keery, H., van der Berg, P., Thompson, J. K. (2004). An evaluation of the Tripatriate Influence Model of body dissatisfaction and eating disturbance with adolescent girls. *Body Image, 1*(3), 237-251. doi: 10.1016/j.bodyim.2004.03.001

Key, A., George, C. L., Beattie, D., Stammers, K., Lacey, H., & Waller, G. (2002). Body image treatment within an inpatient program for anorexia nervosa: the role of mirror exposure in the desensitization process. *International Journal of Eating Disorders, 31*(2), 185-190. doi: 10.1002/eat.10027

Keys, A., Brožek, J., henschel, A., Mickelsen, O., & Taylor, H. L. (1950*). The biology of human starvation*. (2 vols). Oxford: University Press.

Kilteni, K., Maselli, A., Kording, K. P., & Slater, M. (2015). Over my fake body: body ownership illusions for studying the multisensory basis of own-body perception. *Frontiers in Human Neuroscience, 9*, 1-20. doi: 10.3389/fnhum.2015.00141

Knauss, C., Paxton, S. J., Alasker, F. D. (2007). Relationships amongst body dissatisfaction, internalisation of the media body ideal and perceived pressure from media in adolescent girls and boys. *Body Image, 4*(4), 353-360. doi: 10.1016/j.bodyim.2007.06.007

Kolasinski, E. M. (1995). *Simulator sickness in virtual environments.* Retrieved from: http://www.dtic.mil/dtic/tr/fulltext/u2/a295861.pdf

Koskina, A., Campbell, I. C., & Schmidt, U. (2013). Exposure therapy in eating disorders revisited. *Neuroscience & Biobehavioral Reviews, 37*(2), 193–208. doi:10.1016/j.neubiorev.2012.11.010

Leahey, T. M., Crowther, J. H., & Mickelson, K. D. (2007). The frequency, nature, and effects of naturally occurring appearance-focused social comparisons. *Behaviour Therapy, 38*(2), 132-143. doi: 10.1016/j.beth.2006.06.004.

Levi, D. M., Klein, S. A., Aitsebaomo, A. P. (1985). Verner acuity, crowding and cortical magnification. *Vision Research, 25*(7), 963-977

Levine, M. P. & Murnen, S. K. (2009). “Everybody knows that mass media are/are not [pick one] a cause of eating disorders”: a critical review of evidence for a causal link between media, negative body image, and disordered eating in females. *Journal of Social and Clinical Psychology, 28*(1), 9-42. doi: 10.1521/jscp.2009.28.1.9

Littell, R. C., Milliken, G. A., Stroup, W. W., Wolfinger, R. D., & Schabenberber, O. (2006). *SAS for mixed models (2nd ed.)*. Cary, NC: SAS.

Liu, J., Lee, B., McLeod, D. M., & Choung, H. (2018). Framing obesity: Effects of obesity labelling and prevalence statistics on public perceptions. *Health Education & Behavior*, advance online publication. doi: 10.1177/109019811878890

Lombard, M. & Ditton, T. (1997). At the heart of it all: The concept of presence. *Journal of Computer-Mediated Communication*, *3*(2). doi: 10.1111/j.1083-6101.1997.tb00072.x

Longo, M. R. (2016). Distorted Body Representations in Healthy Cognition. *The Quarterly Journal of Experimental Psychology, 70*(3), 378-388. doi: 10.1080/17470218.2016.1143956

Longo, M. R. & Haggard, P. (2012). Implicit body representations and the conscious body image. *Acta Psychologica, 141*(2), 164-168. doi: 10.1016/jactpsy.2012.07015

Longo, M. R., Azañón, E., & Haggard, P. (2010). More than skin deep: body representation beyond primary somatosensory cortex. *Neuropsychologia, 48(3),* 655-668. doi: 10.1016/j.neuropsychologia.2009.08.022

Lopez, C., Tchanturia, K., Stahl, D., & Treasure, J. (2008). Central coherence in eating disorders: a systematic review. *Psychological Medicine, 38*(10), 1393–1404. doi: 10.1017/s0033291708003486

Lowery, S. E., Kurpius, S. E. R., Befort, C., Blanks, E. H., Sollenberger, S., Nicpon, M. F., & Huser, L. (2005). Body image, self-esteem, and health-related behaviours among male and female first year college students. *Journal of College Student Development, 46*(6), 612-623. doi:10.1353/csd.2005.0062

Luce, K. H., Crowther, J.H., & Pole, M. (2008). Eating Disorder Examination Questionnaire (EDE-Q): Norms for undergraduate women. *International Journal of Eating Disorders*, *41(3)*, 273–276. doi: 10.1002/eat.20504

Luce, K. H. & Crowther, J. H. (1999). The reliability of the eating disorder examination – self-report questionnaire version (EDE-Q). *International Journal of Eating Disorders, 25*(3), 349-351. doi: 10.1002/(SICI)1098-108X(199904)25:3<349::AID-EAT15>3.0.CO;2-M

da Luz, F. Q., Sainsbury, A., Mannan, H., Touyz, S., Mitchision, D., Girosi, F., & Hay, P. (2018). An investigation of relationships between eating behaviours, weight/shape overvaluation and mood in the general population. *Appetite, 129*, 19-24. doi: 10.1016/j.appet.2018.06.029

Lykins, A. D., Ferris, T., & Graham, C. A. (2010). Body region dissatisfaction predicts attention to body regions on other women. *Body Image, 11*(4), 404–408. doi: 10.1016/j.bodyim.2014.05.003

Madsen, S. K., Bohon, C., & Feusner, J. D. (2013). Visual processing in anorexia nervosa and body dysmorphic disorder: similarities, differences, and future research directions. *Journal of Psychiatric Research, 47*(10), 1483-1491. doi:10.1016/j.jpsychires.2013.06.003.

Maples-Keller, J. L., Yasinski, C., Manjin, N., & Rothbaum, B. O. (2017). Virtual reality-enhanced extinction of phobias and post-traumatic stress. *Neurotherapeutics, 14*(3), 554-563. doi: 10.1007/s13311-017-0534-y

Maraldo, T. M., Zhou, W., Dowling, J., & Vander Wal, J. S. (2016). Replication and extension of the dial pathway model of disordered eating: the role of negative evaluation, suggestibility, rumination and self-compassion. *Eating Behaviours, 23*, 187-194. doi: 10.1016/j.eatbeh.2016.10.008

Manzoni, G. M., Cesa, G. L., Bacchetta, M., Castelnuovo, G., Conti, S., Gaggioli, A., Mantovani, F., Molinari, E., Cárdenas-Lopez, G., & Riva, G. (2016). Virtual Reality–Enhanced Cognitive–Behavioral Therapy for Morbid Obesity: A

Randomized Controlled Study with 1 Year Follow-Up. *Cyberpsychology, Behavior, and Social Networking, 19*(2), 134–140. doi: 10.1089/cyber.2015.0208

Marco, J. H., Perpiñá, C., & Botella, C. (2013). Effectiveness of cognitive behavioral therapy supported by virtual reality in the treatment of body image in eating disorders: One year follow-up. *Psychiatry Research, 209*(3), 619–625. doi: 10.1016/j.psychres.2013.02.023

Martijn, C., Vanderlinden, M., Roefs, A., Huijding, J., & Jensen, A. (2010). Increasing body satisfaction of body concerned women through evaluative conditioning using social stimuli. *Health Psychology*, *29*(5), 514–520. doi: 10.1037/a0020770

Mazzeo, S. E., & Bulik, C. M. (2009). Environmental and Genetic Risk Factors for Eating Disorders: What the Clinician Needs to Know. *Child and Adolescent Psychiatric Clinics of North America*, 18(1), 67–82. doi:10.1016/j.chc.2008.07.003

McCabe, M. P. & Ricciardelli, L. A. (2005). A longitudinal study of body image and strategies to lose weight and increase muscles among children. *Journal of Applied Developmental Psychology, 26*(5), 559–577. doi: 10.1016/j.appdev.2005.06.007

Meehan, M., Whitton, M., Razzaque, S., Zimmons, P., Insko, B., Combe, G., Lok, B., Scheuermann, T., Naik, S., Jerald, J., Harris, M., Antley, A., & Brooks, F. P. (2002). Physiological reaction and presence in stressful virtual environments. Computer Science, In *ACM SIGGRAPH 2002 Conference Abstracts and Applications, SIGGRAPH 2002* Association for Computing Machinery, Inc.

Meermann, R. (1983). Experimental investigation of disturbances in body image. *International Journal of Eating Disorders, 2*(4), 91-100. doi: 10.1002/1098-108X(198322)2:4<91::AID-EAT2260020416>3.0.CO;2-Z

Menditto, A., Patriarca, M., & Magnusson, B. (2006). *Understanding the meaning of accuracy, trueness and precision*. Accreditation and Quality Assurance, 12(1), 45–47. doi:10.1007/s00769-006-0191-z

Michalak, N. (2016). *Reproducing Hayes' PROCESS Models' results in R*, [blog post]. Retrieved from https://nickmichalak.blogspot.co.uk/2016/07/reproducing-hayess-process-models.html

Miller, K. J., Schalk, G., Fretz, E. E., dan Nijs, M., Ojemann, J. G., & Rao, R. P. N. (2010). Cortical activity during motor execution, motor imagery, and image-based online feedback. *Proceedings of the National Academy of Sciences, 107*(15), 4430-4435. doi: 10.1073/pnas.0913697107.

Miller, J. M. & Bockisch, C. (1997). Where are the things we see? *Nature, 386*, 550-551.

Miloff, A., Lindner, P., Hamilton, W., Reuterskiöld, L., Anderson, G., & Carlbring, P. (2016). Single-session gamified virtual reality exposure therapy for spider phobia vs. traditional exposure therapy: study protocol for a randomised controlled non-inferiority trial. *Trials, 17*(1). doi: 10.1186/s13063-016-1171-1

Mohr, H. M., Zimmermann, J., Röder, C., & Lenz, C. (2010). Separating two components of body image in anorexia nervosa using fMRI. *Psychological Medicine, 40*(09), 1519–1529. doi: 10.1017/s0033291709991826

Molina, K. M., Estrella, M. L., Rivera-Olmedo, N., Frisard, C., Lemon, S., & Rosel, M. C. (2018). It weigh(t)s on you. Everyday discrimination and adiposity among Latinos. *Obesity, 26*(9), 1474-1480. doi: 10.1002/oby.22248

Mölbert, S. C., Klein, L., Thaler, A., Mohler, B. J., Brozzon, C., Martus, P., Harnath, H-O., Zipfel, S., & Giel, K. E. (2017a). Depictive and metric size estimation in anorexia nervosa and bulimia nervosa: a systematic review and meta-analysis. *Clinical Psychology Review, 57*, 21-31. doi: 10.1016/j.cpr.2017.08.005

Mölbert, S. C., Thaler, A., Mohler, B. J., Streuber, S., Romero, J., Black, M. J., Zipfel, S., Karnath, H-O., Giel, K. E. (2017b). 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, 48*(4), 642-653. Doi: 10.1017/S0033291717002008

Mond, J. M., Myers, T. C., Crosby, R. D., Hay, P. J., Rodgers, B., Morgan, J. F., Lacey, J. H., & Mitchell, J. E. (2008). *Screening for eating disorders in primary care: EDE-Q versus SCOFF*. *Behaviour Research and Therapy, 46*(5), 612-622. doi: 10.1016/j.brat.2008.02.003

Mond, J.M., Hay, P.J., Rodgers, B., & Owen, C. (2006). Eating Disorder Examination Questionnaire (EDE-Q): Norms for young adult women. *Behaviour Research and Therapy*, *44*, 53–62. doi: 10.1016/j.brat.2004.12.003

Monteath, S. A. & McCabe, M. P. (1997). The influence of societal factors on the female body image. *Journal of Social Psychology*, *137*(6). 708-727. doi: 10.1080/00224549709595493

Moradi, B., Dirks, D., & Matteson, A. V. (2005). Roles of sexual objectification experiences and internalisation of standards of beauty in eating disorder symptomatology. A test and extension of objectification theory*. Journal of Counselling Psychology, 52*(3), 420-428. doi: 10.1037/0022-0167.52.3.420

Moschos, M. M., Gonidakis, F., Varsou, E., Markopoulos, I., Rouvas, A., Ladas, I., & Papadimitriou, G. N. (2010). Anatomical and functional impairment of the retina and optic nerve in patients with anorexia nervosa without vision loss. *British journal of Ophthalmology, 95*(8), 1128-1133. doi: 10.1136/bjo.2009.177899

Moseley, G. L., Gallace, A., & Spence, C. (2012). Bodily illusions in health and disease: Physiological and clinical perspectives and the concept of a cortical ‘body matrix’.

Neuroscience & Biobehavioral Reviews, 36(1), 34-46. Doi: 10.1016/j.neubiorev.2011.03.013

Moseley, G. L., Parsons, T. J., & Spence, C. (2008). Visual distortion of a limb modulates the pain and swelling evoked by movement. *Current Biology, 18*(22), R1047-R1048. doi: 10.1016/j.cub.2008.09.031

Motter, B. C. & Belky, E. J. (1998). The guidance of eye movements during active visual search. *Vision Research, 38*(12), 1805–1815. doi:10.1016/s0042-6989(97)00349-0

Murnen, S. K. (2011). Gender and body images. In Cash, T. F. & Smolak, L. (Eds.). *Body image: a handbook of science, practice, and prevention* (pp.173-179). New York: Guildford Press.

Murray, R. F., & Gold, J. M. (2004). Troubles with bubbles. *Vision Research, 44*(5), 461–470. doi: 10.1016/j.visres.2003.10.006

Myers, T. A. & Crowther, J. H. (2009). Social comparison as a predictor of body dissatisfaction. A meta-analytic review. *Journal of Abnormal Psychology, 118*(4), 683-698. doi: 10.1037/a0016763

Neumark-Sztainer, D, Bauer, K. W. Friend, S., Hannah, P. J., Story, M., & Berge, J. M. (2010). Family weight talk and dieting: how much do they matter for body dissatisfaction and disordered eating behaviours in adolescent girls? *Journal of Adolescent Health, 47*(3), 270-276. doi: 10.1016/j.jadohealth.2010.02.001

Neumark-Sztainer, D., Paxton, S. J., Hannah, P. J., Haines, J., & Story, M. (2006). Does body satisfaction matter? Five-year longitudinal associations between body satisfaction and health behaviours in adolescent females and males. *Journal of Adolescent Health, 39*(2), 244-251. doi: 10.1016/j.jadohealth.2005.12.001

Neumark-Sztainer, D., Wall, M., Guo, J., Story, M., Haines, J. & Eisenberg, M. (2006). Obesity, disordered eating, and eating disorders in a longitudinal study of adolescents: how do dieters fare 5 years later? *Journal of the American Dietetic Association, 106*(4), 559-568. doi: 10.1016/j.jada.2006.01.003

Newport, R., Pearce, R., & Preston, C. (2010). Fake hands in action: embodiment and control of supernumerary limbs*. Experimental Brain Research, 204*(3), 385-395. doi: 10.1007/s00221-009-2104-y

Nevid, J. S. & McClelland, N. (2010). Measurement of implicit and explicit attitudes toward Barack Obama. *Psychology & Marketing, 27*(10), 989-100. doi: 10.1002/mar.20369

O'Dea, J. A. & Abraham, S. (2000). Improving the body image, eating attitudes, and behaviours of young male and female adolescents: a new educational approach that focuses on self-esteem. *International Journal of Eating Disorders, 28*(1), 43-57. doi: 10.1002/(sici)1098-108x(200007)28:1<43::aid-eat6>3.0.co;2-d

Ouwens, M. A., van Strien, T., van Leeuwe, J. F. J., & van der Staak, C. (2009). The dual pathway model of overeating. Replication and extension with actual food consumption. *Appetite, 52*(1), 234-237. doi: 10.1016/j.appet.2008.07.010

Paap, c. E. & Gardner, R. M. (2011). Body image disturbance and relationship satisfaction among college students. *Personality and Individual Differences, 51*(6), 715-719. doi: 10.1016/j.paid.2011.06.019

Paillard, J. (1999). Body schema and body image: a double dissociation in deafferented patients. In: Gantchev, G. N., Mori, S., & Massion, J. (Eds.), *Motor control, today and tomorrow* (pp. 197-214*).* Sofia: Academic Publishing House.

Paillard, J. (1997). Divided body schema and body image in deafferented patients. In: Brain and Movement: Int. Symp. Motor control. St-Petersburg – Moscow

(Abstract). In: V. S. Gurfinkel & Yu. S, Levik (Eds), Institute for Information and Transmission problems RAS Moscow.

Paillard, J. (1991). Knowing where and knowing how to get there. In: Paillard, J. (Ed.) *Brain and space* (pp. 461-481). Oxford: Oxford University Press.

Paillard, J., Michel, F., & Stelmach, G. (1983). Localisation without content: a tactile analogue of “blind sight”. *Archives of Neurology, 40*(9), 548. doi: 10.1001/archneur.1983.04050080048008

Palmer, B. (2003). Concepts of Eating Disorders. In Treasure, J. Schmidt, U. & van Furth, E. (Eds.), *Handbook of Eating Disorders* (pp. 1-10). West Sussex: John Wiley & Sons.

Parsons, T. D. & Rizzo, A. A. (2008). Affective outcomes of virtual reality exposure therapy for anxiety and specific phobias: A meta-analysis. *Journal of Behavior Therapy and Experimental Psychiatry, 39*(3), 250–261. doi: 10.1016/j.jbtep.2007.07.007

Paxton, S. J., Neumark-Sztainer, D., Hannan, P. J., & Eisenberg, M. E. (2006). Body dissatisfaction prospectively predicts depressive mood and low self-esteem in adolescent girls and boys. *Journal of Clinical Child and Adolescent Psychology, 35*(4), 539–549. doi: 10.1207/s15374424jccp3504_5

Paxton, S. J., Schutz, H. K., Wertheim, E. H., & Muir, S. L. (1999). Friendship clique and peer influences on body image concerns, dietary restraint, extreme weight-loss behaviors, and binge eating in adolescent girls. *Journal of Abnormal Psychology, 108*(2), 255–266. doi: 10.1037/0021-843x.108.2.255

Payne, K. B., Burkley, M. A., Stokes, M. B. (2008). Why do implicit and explicit attitudes tests diverge? The role of structural fit. *Journal of Personality and Social Psychology, 94*(1), 16-31. doi: 10.1037/0022-3514.94.1.16

Pelli, D. & Tillman, K. A. (2008). The uncrowded window of object recognition. *Nature Neuroscience, 11*(10), 1129-1135. doi: 10.1038/nn.2187

Pennesi, J.-L., & Wade, T. D. (2016). A systematic review of the existing models of disordered eating: Do they inform the development of effective interventions? *Clinical Psychology Review*, 43, 175–192. doi:10.1016/j.cpr.2015.12.004

Penton-Voak, I. S., Bate, H., Lewis, G., & Munafò, M. R. (2012). Effects of emotion perception training on mood in undergraduate students: randomised controlled trial. *British Journal of Psychiatry*, *201*(01), 71–72. doi: 10.1192/bjp.bp.111.107086

Penton-Voak, I. S., Thomas, J., Gage, S. H., McMurran, M., McDonald, S., Munafò, M. R. (2013). Increasing recognition of happiness in ambiguous facial expressions reduces anger and aggressive behaviour. *Psychological Science, 24*(5), 688–697. doi: 10.1177/0956797612459657

Perpiñá, C., Botella, C., Banos, R., Marco, H., Alcaniz, M., & Quero, S. (1999). Body Image and Virtual Reality in Eating Disorders: Is Exposure to Virtual Reality More Effective than the Classical Body Image Treatment? *CyberPsychology & Behavior, 2*(2), 149–155. doi: 10.1089/cpb.1999.2.149

Peterson, C. B., Crosby, R. D., Wonderlich, S. A., Joiner, T., Crow, S. J., Mitchell, J. E., Bardone-Cone, A. M., Klein, M. & le Grange, D. (2007). Psychometric properties of the eating disorder examination-questionnaire: Factor structure and internal consistency. *International Journal of Eating Disorders, 40*(4), 386–389. doi: 10.1002/eat.20373

Petkova, V. I., & Ehrsson, H. H. (2008). If I Were You: Perceptual Illusion of Body Swapping. *PLoS ONE, 3*(12), e3832. doi: 10.1371/journal.pone.0003832

Pike, K. M. (1998). Long-term course of anorexia nervosa. Clinical Psychology Review, 18(4), 447–475. doi:10.1016/s0272-7358(98)00014-2

Piryankova, I. V., Stefanucci, J. K., Romero, J., De La Rosa, S., Black, M. J., & Mohler, B. J. (2014a). Can I recognize my body's weight? The influence of shape and texture on the perception of self. *ACM Transaction on Applied Perception, 11*(3), 1–18. doi: 10.1145/2641568

Piryankova, I. V., Wong, H. Y., Linkenauger, S. A., Stinson, C., Longo, M. R., Bülthoff, H. H., & Mohler, B. J. (2014b). Owning an Overweight or Underweight Body: Distinguishing the Physical, Experienced and Virtual Body. *PLoS ONE, 9*(8), e103428. doi: 10.1371/journal.pone.0103428

Pitron, V. & de Vignemont, F. (2017). Beyond differences between the body schema and the body image: insights from body hallucinations. *Consciousness and Cognition, 53,* 115-121. doi: 10.1016/j.concog.2017.06.006

Polivy, J. (1996). Psychological consequence of food restriction. *Journal of the American Dietetic Association, 96*(6), 589-592. doi: 10.1016/s0002-8223(96)00161-7

Polivy, J. & Herman, C. P. (2002). Causes of eating disorders. *Annual Review of Psychology, 53*(1), 187–213. doi: 10.1146/annurev.psych.53.100901.135103

Pollatos, O., Kurz, A., Albrecht, J., Schreder, T., Kleeman A.M., Schöpf, V., Kopietz, R., Wiesmann, M., & Schandry, R. (2008). Reduced perception of bodily signals in anorexia nervosa. *Eating Behaviors, 9*(4): 381-388. Doi: 10.1016/j.eatbeh.2008.02.001.

Pope, H., Phillips, K., & Olivardia, R. (2000). *The Adonis complex*. New York: Free Press.

Posner, M. I., Snyder, C. R., & Davidson, B. J. (1980). Attention and the detection of signals. Journal of Experimental Psychology: General, 109(2), 160–174. doi:10.1037/0096-3445.109.2.160

Posner, M. I. (1980). Orienting of attention. Quarterly Journal of Experimental Psychology, 32(1), 3–25. doi:10.1080/00335558008248231

Poulton, E. C. (1989). *Bias in Quantifying Judgements*. Hove: Erlbaum.

Preacher, K. J. & Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior Research Methods, 40*(3), 879-891. doi: 10.3758/brm.40.3.879

Preston, C. & Ehrsson, H. H. (2018). Implicit and explicit change in body size satisfaction evoked by body size illusions: Implications for eating disorder vulnerability in women. *PlosONE 13*(6):e0199426. doi: 10.1371/journal.pone.0199426

Preston, C., & Ehrsson, H. H. (2016). Illusory Obesity Triggers Body Dissatisfaction Responses in the Insula and Anterior Cingulate Cortex. *Cerebral Cortex, 26*(12), 4450–4460. doi: 10.1093/cercor/bhw313

Preston, C. & Ehrsson, H. H. (2014). Illusory changes in body size modulate body satisfaction in a way that is related to non-clinical eating disorder psychopathology. PlosONE, 9(1): e85773. doi: 10.1371/journal.pone.0085773

Probst, M., Pieters, G., & Vanderlinden, J. (2008). Evaluation of body experience questionnaires in eating disorders in female patients (AN/BN) and nonclinical participants. *International Journal of Eating Disorders, 41*(7), 657-665. doi:10.1002/eat.20531

Probst, M., Vandereycken, W., Van Coppenolle, H., & Pieters, G. (1998). Body size estimation in anorexia nervosa patients: the significance of overestimation. *Journal of Psychosomatic Research, 44*(3-4), 451-456. doi: 10.1016/s0022-3999(97)00270-5

Probst, M., Vandereycken, W., Van Coppenolle, H., & Pieters, G. (1995). Body size estimation in eating disorder patients: testing the video distortion method on a life-sized screen. *Behaviour Research and Therapy, 33*(8), 985-990.

Puccio, F., Fuller-Tyszkiewicz, M., Ong, D., & Krug, I. (2015). A systematic review and meta-analysis on the longitudinal relationship between eating pathology and depression. *International Journal of Eating Disorders*, *49*(5), 439-454.

Puhl, R. M., Andreyeva, T., & Brownell, K. D. (2008). Perceptions of weight discrimination: prevalence and comparison to race and gender discrimination in America. *International Journal of Obesity, 32*(6), 992–1000. doi: 10.1038/ijo.2008.22

Quinn, D. M., Kallen, R. W., Twenge, J. M., & Fredrickson, B. L. (2006). The disruptive effect of self-objectification on performance. *Psychology of Women Quarterly, 30*(1), 59–64. doi: 10.1111/j.1471-6402.2006.00262.x

R Development Core Team (2008). *R: a language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

Reason, J. T. & Brand, J. J. (1975). *Motion sickness*. London: Academic Press.

Reitman, E. E. & Cleveland, S. E. (1964). Changes in body image following sensory deprivation in schizophrenic and control groups. *The Journal of Abnormal and Social Psychology, 68*(2), 168-176. doi: 10.1037/h0046252

Revelle, W. (2016). Psych: Procedures for personality and psychological research. *R package*.

Rhodes, G., Jeffery, L., Boeing, A. & Calder, A. J. (2013). Visual coding of human bodies: Perceptual aftereffects reveal norm-based, opponent coding of body identity. *Journal of Experimental Psychology: Human Perception and Performance, 39*(2), 313-317. doi: 10.1037/a0031568

Roth, M., Decety, J., Raybaudi, M., Massarelli, R., Delon-Martin, C., Segebarth, C., Morand, S., Gemigani, A., Décorps, M., & Heannerod, M. (1996). Possible involvements of primary motor cortex in mentally simulated movement: A functional magnetic resonance imaging study. *Neuroreport, 7*(7), 1280-1284.

Rilling, J.K., Kaufman T.L., Smith, E.O., Patel R., & Worthman, C.M. (2009). Abdominal depth and waist circumference as influential determinants of human female attractiveness. *Evolution and Human Behavior, 30*, 21–31. doi: 10.1016/j.evolhumbehav.2008.08.007

Riva, G. (2012). Neuroscience and eating disorders: the allocentric lock hypothesis. *Medical Hypotheses, 78*(2), 254-257. doi: 10.1016/j.mehy.2011.10.039

Riva, G. & Gaudio, S. (2012). Allocentric lock in anorexia nervosa: new evidences from neuroimaging studies. *Medical Hypotheses, 79*(1), 113–117. doi: 10.1016/j.mehy.2012.03.036

Riva, G. (1998). Virtual environment for body image modification: Virtual reality system for the treatment of body image disturbances. *Computers in Human Behaviour*, *14*(3), 477–490. doi:10.1016/s0747-5632(98)00018-1

Riva, G. & Melis, L. (1997). Virtual reality for the treatment of body image disturbances. In G. Riva (Ed.) *Virtual reality in Neuro-Psycho-Physiology* (pp. 95-111). Amsterdam: IOS Press.

Riva, G. & Waterworth, J. A. (2003). Presence and the Self: a cognitive neuroscience approach. Retrieved from: http://www8.informatik.umu.se/~jwworth/Riva-Waterworth.htm

Robinson, A., Safer, D. L., Austin, J. L., & Etkin, A. (2015). Does implicit emotion regulation in binge eating disorder matter? *Eating Behaviors, 18*, 186–191. doi:10.1016/j.eatbeh.2015.05.011

Robinson, E., & Kirkham, T. C. (2013). Is he a healthy weight? Exposure to obesity changes perception of the weight status of others. *International Journal of Obesity, 38*(5), 663–667. doi: 10.1038/ijo.2013.154

Rodin, J., Silberstein, L. & Striegel-Moore, R. (1984). Women and weight: a normative discontent. *Nebraska Symposium on Motivation, 32*, 267-307.

Roefs, A. Jansen, A., Moresi, S., Willems, P., van Grootel, S., & van der Borgh, A. (2008). Looking good. BMI, attractiveness bias and visual attention. *Appetite, 51*(3), 552-555. doi: 10.1016/j.appet.2008.04.008

Rosen, J. C. (1997). Cognitive-behavioral body image therapy. In D. M. Garner, & P. E. Garfinkel (Eds.). *Handbook of treatment for eating disorders* (2nd ed.). New York: The Guilford Press.

Rosen, J. C., Jones, A., Ramirez, E., & Waxman, S. (1996). Body shape questionnaire: studies of validity and reliability. *International Journal of Eating Disorders, 20*(3), 315-319. doi: 10.1002/(sici)1098-108x(199611)20:3<315::aid-eat11>3.0.co;2-z

Rosenberg, M. (1965). *Society and the adolescent self-image*. Princeton, NJ: Princeton University Press.

Rosseel, Y. (2012). Lavaan: an R package for structural equation modelling*. Journal of Statistical Software, 48*(2), 1-36. doi: 10.18637/jss.v048.o02

Roy, M. & Forest, F. (2007). Assessment of body-image distortion in eating and weight disorders: the validation of a computer-based tool (Q-BID). *Eating and Weights Disorders, 12*(1), 1-11. doi: 10.1007/bf03327766

Ryan, A., & Nicklas, B. (1999). Age-related changes in fat deposition in mid-thigh muscle in women: relationships with metabolic cardiovascular disease risk factors. *International Journal of Obesity, 23*(2), 126–132. doi: 10.1038/sj.ijo.0800777

Ryu, D., Abernethy, B., Mann, D. L., Poolton, J. M., & Gorman, A. D. (2013). The role of central and peripheral vision in expert decision making. *Perception, 42*, 591-607.

Sala, L. Mirabel-Sarron, C., Pham-Scottez, A., Blanchet, A., Rouillon, F., & Gorwood, P. (2012). Body dissatisfaction is impaired but the ideal silhouette is unchanged during weight recovery in anorexia nervosa female patients. *Eating and Weight Disorders, 17*(2), e109-e115. doi: 10.1007/bf03325334

Sambo, C. F., & Iannetti, G. D. (2013). Better Safe Than Sorry? The Safety Margin Surrounding the Body Is Increased by Anxiety. *Journal of Neuroscience, 33*(35), 14225–14230. doi: 10.1523/jneurosci.0706-13.2013

Schaefer, L. M., Burke, N. L., Anderson, L. M., Thompson, K. J., Heinberg, L. J., Bardone-Cone, A. M., Higgins Neyland, M. K., Fredrick, D. A., Anderson, D. A., Schaumberg, K., Nerini, A., Stefanile, C., Dittmar, H., Klump, K. L., Vercellone, A. C., & Paxton, S. J. (2018). Comparing internalisation of appearance ideals and appearance related-pressures among women from the United State, Italy, England, and Australia. *Eating and Weight Disorders – Studies on Anorexia, Bulimia and Obesity* (advanced online publication) doi:10.1007/s40519-018-0544-8

Schaefer, L. M. & Thompson, J. K. (2014). The development and validation of the physical appearance comparison scale-revised (PACS-R). *Eating behaviours, 15*(2), 209-217. doi: 10.1016/jearbeh.2014.01.001

Schafran, R., & Fairburn, C. G. (2002). A new ecologically valid method to assess body size estimation and body size dissatisfaction*. International Journal of Eating Disorders, 32*(4), 458–465. doi: 10.1002/eat.10097

Schilder, P. (1935). *The image and appearance of the human body*. New York: International Universities Press.

Schmitt, D. P. & Allik J. (2005). Simultaneous administration of the Rosenberg self-esteem scale in 53 nations: exploring the universal and culture-specific features of global self-esteem. *Journal of Personality and Social Psychology, 89*(4), 623-642. doi: 10.1037/0022-3514.89.4.623

Schonfeld, W. A. (1966). Body image disturbances in adolescents: IV. Influence of family attitudes and psychopathology. Archives of General Psychiatry, 15(1), 16-21. doi: 10.1001/archpsyc.1966.01730130018003

Schwoebel, J., & Coslett, H. B. (2001). Evidence for multiple, distinct representations of the human body. *Journal of Cognitive Neuroscience, 17*, 543-553. Doi: 10.1162/0898929053467587.

Schwoebel, J., Friedman, R., Duda, N., & Coslett, H. B. (2001). Pain and the body schema. Evidence for peripheral effects on mental representations of movement. *Brain, 124*(10), 2098–2104. doi:10.1093/brain/124.10.2098

Secord, P. F. & Jourard, S. M. (1953). The Appraisal of Body-cathexis: Body-Cathexis and the self. *Journal of Consulting Psychology, 17*(5), 343–347. doi: 10.1037/h0060689

Shepherd, H., & Ricciardelli, L. A. (1998). Test of Stice’s dual pathway model: Dietary restraint and negative affect as mediators of bulimic behavior*. Behaviour Research and Therapy, 36*(3), 345–352. doi:10.1016/s0005-7967(98)00033-3

Shih, P. B., & Woodside, D. B. (2016). Contemporary views on the genetics of anorexia nervosa. European Neuropsychopharmacology, 26(4), 663–673. doi:10.1016/j.euroneuro.2016.02.008

Shroff, H. & Thompson, K. (2006a). The tripatriate influence model of body image and eating disturbance: A replication with adolescent girls. *Body Image, 3*(1), 17-23. doi: 10.1016/j.bodyim.2005.10.004

Shroff, H. & Thompson, K. (2006b). Peer influences, body image dissatisfaction, eating dysfunction and self-esteem in adolescent girls. *Journal of Health Psychology, 11*(4), 533-551. doi: 10.1177/1359105306065015

Sirigu, A., Duhamel, J. R., Cohen, L., Pillon, B., Dubois, B, & Agid, Y. (1996). The mental representation of hand movements after parietal cortex damage. *Science, 273*(5281), 1564-1568. doi: 10.1126/science.273.5281.1564.

Skrzypek, S., Wehmeier, P. M., & Remschmidt, H. (2001). Body image assessment using body size estimation in recent studies on anorexia nervosa. A brief review. *European Child & Adolescent Psychiatry, 10*(4), 215–221. doi: 10.1007/s007870170010

Slade, P. D. (1988). Body image in anorexia nervosa. *British Journal of Psychiatry, 153*(Suppl. 2), 20-22.

Slade, P., & Russell, G. (1973). Awareness of body dimensions in anorexia nervosa: cross-sectional and longitudinal studies. *Psychological Medicine*, *3*(02), 188. doi: 10.1017/s0033291700048510

Slater, A., Varsani, N., Diedrichs, P.C. (2017). #fitspo or #loveyourself? The impact of fitspiration and self-compassion Instagram images on women's body image, self-compassion, and mood. *Body Image, 22*, 87-96. doi: 10.1016/j.bodyim.2017.06.004

Slater, A. & Tiggemann, M. (2002). A test of objectification theory in adolescent girls. *Sex Roles, 46*(9-10), 343-349. doi: 10.1023/A:1020232714705

Slater, M. & Wilbur, S. (1997). A Framework for Immersive Virtual Environments (FIVE): Speculations on the role of Presence in Virtual Environments. *Presence: Teleoperators & Virtual Environments, 6*(6), 603–616. doi: 10.1162/pres.1997.6.6.603

Slater, M., Usoh, M. & Steed, A. (1994). Depth of presence in virtual environments. *Presence: Teleoperators and virtual environments*, *3*(2), 130–144. doi: 10.1162/pres.1994.3.2.130

Slevec, J. & Tiggemann, M. (2010). Attitudes towards cosmetic surgery in middle-aged women: body image, aging anxiety, and the media. *Psychology of Women Quarterly*, *34*(1), 65–74. doi:10.1111/j.1471-6402.2009.01542.x

Smeets, M. A. M., Ingleby, D. J., Hoek, H. W. & Panhuysen, E. M. (1999). Body size perception in anorexia nervosa: a signal detection approach. *Journal of Psychosomatic Research, 46*(5), 465–477. doi: 10.1016/s0022-3999(99)00005-7

Smeets, M. A. M. (1997). The rise and fall of body size estimation research in anorexia nervosa: a review and reconceptualization. European Eating Disorder Reviews, 5(2), 75-95. doi: 10.1002/(sici)1099-0968(199706)5:2<75::aid-erv190>3.0.co;2-a

Smeets, M. A. M., Smit, F., Panhuysen, G. E. M., & Ingleby, J. D. (1997). The influence of methodological differences on the outcomes of body size estimation studies in anorexia nervosa. *British Journal of Clinical Psychology, 36*(2), 263-277. doi: 10.1111/j.2044-8260.1997.tb01412.x

Smith, A. J. (2009). Acting on (bodily) experience. *Psyche, 15*(1), 82-99.

Smith, K. L., Tovée, M. J., Hancock, P. J., Bateson, M., Cox, M. A. A., Cornelissen, P. L. (2007). An analysis of body shape attractiveness based on image statistics: Evidence for a dissociation between expressions of preference and shape discrimination. *Visual Cognition, 15*(8), 927-953. doi: 10.1080/13506280601029515

Smolak, L. & Thompson, J. K. (2009). *Body image, eating disorders, and obesity in youth. Assessment, prevention, and treatment* (2nd Ed.). Washington: American Psychological Association.

Spitoni, G.F., Serino, A., Cotugno, A., Mancini, F., Antonucci, G., & Pizzamiglio, L. (2015). The two dimensions of the body representation in women suffering from Anorexia Nervosa. *Psychiatry Research, 15*; 230(2), 181-8. doi: 10.1016/j.psychres.2015.08.03

Sprinkles, S. D., Lurie, D., Insko, S. L., Atkinson, G., Jones, G. L., Logan, A. R., & Bissada, N. N. (2002). Criterion validity, severity cut scores and test-retest reliability of the beck depression inventory-II in a university counselling centre sample. *Journal of Counselling Psychology*, *49*(3). 381-385. doi: 10.1037/0022-0167.49.3.381.

Stanislaw, H., & Todorov, N. (1999). Calculation of signal detection theory measures. *Behavior Research methods, Instruments & Computers, 31*(1), 137–149. doi: 10.3758/bf03207704

Stewart, A. D., Klein, S., Young, J., Simpson, S., Lee, A. J., Harrild, L., Crockett, P., & Benson, P. J. (2012). Body image, shape, and volumetric assessments using 3D whole body laser scanning and 2D digital photography in females with a diagnosed eating disorder: Preliminary novel findings. *British Journal of Psychology, 103*(2), 183–202. doi: 10.1111/j.2044-8295.2011.02063.x

Stice, E. (2002). Risk and maintenance factors for eating pathology: A meta-analytic review. *Psychological Bulletin, 128*(5), 825-848. doi: 10.1037/0033-2909.128.5.825

Stice, E. (2001). A prospective test of the dual-pathway model of bulimic pathology: Mediating effects of dieting and negative affect. *Journal of Abnormal Psychology, 110*(1), 124-135. doi: 10.1037/0021-843x.110.1.124

Stice, E., Spangler, D., & Agras, W. S. (2001). Exposure to Media-Portrayed Thin-Ideal Images Adversely Affects Vulnerable Girls: A Longitudinal Experiment*. Journal of Social and Clinical Psychology, 20*(3), 270–288. doi: 10.1521/jscp.20.3.270.22309

Stice, E., Akutagawa, D., Gaggar, A., & Agras, W. S. (2000). Negative affect moderates the relation between dieting and binge eating. *International Journal of Eating Disorders, 27*(2), 218-229. doi: 10.1002/(sici)1098-108x(200003)27:2<218::aid-eat10>3.0.co;2-1

Stice, E. & Agras, S. W. (1998). Predicting onset and cessation of bulimic behaviors during adolescence: a longitudinal grouping analysis. *Behaviour Therapy, 29*(2), 257-276. doi: 10.1016/s0005-7894(98)80006-3

Stice, E. & Bearman, S. K. (2001). Body-image and eating disturbances prospectively predict increases in depressive symptoms in adolescent girls: A growth curve analysis. *Developmental Psychology, 37*(5), 597-607. doi: 10.1037/0012-1649.37.5.597

Stice, E., Chase, A., Stormer, S. & Appel, A. (2001). A randomised trial of dissonance-based eating disorder prevention program. *International Journal of Eating Disorders, 29*(3), 247–262. doi: 10.1002/eat.1016

Stice, E., Mazotti, L., Krebs, M., & Martin, S. (1998). Predictors of adolescent dieting behaviours: a longitudinal study. *Psychology of Addictive Behaviours, 12*(3), 195-205. doi: 10.1037/0893-164x.12.3.195

Stice, E. & Shaw, H. E. (2002). Role of body dissatisfaction in the onset and maintenance of eating pathology: A synthesis of research findings. *Journal of Psychosomatic Research, 53*(5), 985-993. doi: 10.1016/s0022-3999(02)00488-9

Stice, E., & Shaw, H. E. (1994). Adverse Effects of the Media Portrayed Thin-Ideal on Women and Linkages to Bulimic Symptomatology. *Journal of Social and Clinical Psychology, 13*(3), 288–308. doi: 10.1521/jscp.1994.13.3.288

Striegel-Moore, R., Rossellin, F., Perrin, N., DeBar, L., Wilson, G. T., May, A., & Kraemer, H. C. (2008). Gender differences in the prevalence of eating disorder symptoms. *International Journal of Eating Disorders, 42*(5), 471-474. Doi: 10.1002/eat.20625

van Strien, T. V., Engels, R. C. M. E., Leeuwe, J. V., & Snoek, H. M. (2005). The Stice model of overeating: Tests in clinical and non-clinical samples. *Appetite, 45*(3), 205-213. doi: 10.1016/j.appet.2005.08.004

Strober, M., Freeman, R. & Morrell, W. (1998). The long-term course of sever anorexia nervosa in adolescents: Survival analysis of recovery, relapse, and outcome predictors over 10-15 years in a prospective study. *International Journal of Eating Disorders, 22*(4), 339-360. doi: 10.1002/(sici)1098-108x(199712)22:4<339::aid-eat1>3.0.co;2-n

Stunkard, A., Sorensen, T. & Schulsinger, F. (1983). Use of the Danish Adoption Register for the study of obesity and thinness. *Research Publications – Association for Research in Nervous and Mental disease, 60*, 115-120.

Swami, V. et al…. (2010). The attractive female body weight and female body dissatisfaction in 26 countries across 10 world regions: results of the international body project I. *Personality and Social Psychology Bulletin, 36*(3), 309-325. doi: 10.1177/0146167209359702

Sypeck, M. F., Gray, J. J., & Ahrens, A. H. (2004). No longer just a pretty face: fashion magazines' depictions of ideal female beauty from 1959 to 1999. *International Journal of Eating Disorders, 36*(3), 342-347. doi: 10.1002/eat.20039

Szostak, N. M. (2018). *Negative body image and cognitive biases to body size.* (Doctoral dissertation). Retrieved from: https://hydra.hull.ac.uk/resources/hull:16444

Taylor, M. J. & Cooper, P. J. (1986). Body size overestimation and depressed mood. *British Journal of Clinical Psychology, 25*(2), 153-154. doi: 10.1111/j.2044-8260.1986.tb00688.x

Taylor, M. J. (1987). *The nature and significance of body image disturbance*. (Doctoral dissertation). Retrieved from: https://www.psyctc.org/tools/bsq/thesis/

Taylor-Clarke, M., Jacobsen, P., & Haggard, P. (2004). Keeping the world a constant size: object constancy in human touch. *Nature Neuroscience, 7*(3), 219–220. doi: 10.1038/nn1199

Tanner, W. P. & Swets, J. A. (1954). A decision-making theory of visual detection. *Psychological Review, 61*(6), 401–409. doi: 10.1037/h0058700

Thaler, A., Piryankova, I., Stefanucci, J. K., Pujades, S., de la Rosa, S., Streuber, S., Romero, J., Black, M., & Mohler, B. J. (2018). Visual Perception and Evaluation of Photo-Realistic Self-Avatars From 3D Body Scans in Males and Females. Frontiers in ICT, 5. doi: 10.3389/fict.2018.00018

Thornton, L. M., Mazzeo, S. E., & Bulik, C. M. (2010). The Heritability of Eating Disorders: Methods and Current Findings. Current Topics in Behavioral Neurosciences, 141–156. doi:10.1007/7854_2010_91

Tiggemann, M. (2011). Sociocultural perspectives on human appearance and body image. In Cash, T. F. & Smolak, L. (Eds*.). Body image: a handbook of science, practice, and prevention* (2nd ed.), (pp39-47), New York: The Guildford Press.

Tiggemann, M. (2004). Body image across the adult life span: stability and change. *Body Image, 1*(1), 29-41. doi: 10.1016/s1740-1445(03)00002-0

Tiggemann, M. (2003). Media exposure, body dissatisfaction and disordered eating: television and magazines are not the same! *European Eating Disorders Review, 11*(5), 418-430. doi: 10.1002/erv.502

Tiggemann, M. & Slater, A. (2003). Thin ideals in music television: a course of social comparison and body dissatisfaction*. International Journal of Eating Disorders, 35*(1), 48-58. doi: 10.1002/eat.10214

Tiggemann, M., & Kuring, J. K. (2004). The role of body objectification in disordered eating and depressed mood. *British Journal of Clinical Psychology, 43*(3), 299-311. doi: 10.1348/0144665031752925

Tiggemann, M. & Lynch, J. E. (2001). Body image across the life span in adult women: the role of self-objectification. *Developmental Psychology, 37*(2), 243-253. doi: 10.1037/0012-1649.37.2.243

Tiggemann, M. & Slater, A. (2001). A test of objectification theory in former dancers and non-dancers. *Psychology of Women Quarterly, 25*(4), 57-64. doi: 10.1111.1471-6402.00007

Thompson, J. K., & Stice, E. (2001). Thin-ideal internalization: Mounting evidence for a new risk factor for body image disturbance and eating pathology. *Current Directions in Psychological Science, 10*(5), 181-183. doi: 10.1111/1467-8721.00144

Thompson, J. K., Heinberg, L. J., Altabe, M., & Tantleff-Dunn, S. (1999). *Exacting beauty: theory, assessment, and treatment of body image disturbance*. Washington DC: American Psychological Association.

Thompson, J. K. & Spana, R. E. (1988). The adjustable light beam method for the assessment of size estimation accuracy: description, psychometrics and normative data. *International Journal of Eating Disorders, 7*(4), 521–526. doi: 10.1002/1098-108x(198807)7:4<521::aid-eat2260070410>3.0.co;2-h

Todd, J. (1955). The syndrome of Alice in Wonderland. *Canadian Medical Association Journal, 73*(9), 701-704.

Tovée, M. J., Benson, P. J., Emery, J. L., Mason, S. M., & Cohen-Tovée, E. M. (2003). Measurement of body size and shape perception in eating-disordered and control observers using body-shape software. *British Journal of Psychology, 94*(4), 501-516. doi: 10.1348/000712603322503060

Tovée, M. J., Hancock, P. J. B., Mahmoodi, S., Singleton, B. R. R. & Cornelissen, P. L. (2002). Human female attractiveness: waveform analysis of body shape. *Proceedings of the Royal Society of London B: Biological Sciences, 269*(1506), 2205-2213. ISSN 0950-1193

Tovée, M. J., & Cornelissen, P. L. (2001). Female and male perceptions of female physical attractiveness in front-view and profile. *British Journal of Psychology, 92*(2), 391–402. doi:10.1348/000712601162257

Tovée, M. J., Maisey, D. S., Emery, J. L., & Cornelissen, P.L. (1999). Visual cues to female physical attractiveness. *Proceedings of the Royal Society of London Biological Sciences, 266*(1415), 211-218. doi: 10.1098/rspb.1999.0624

Traub, A. C., & Orbach, J. (1964). Psychophysical studies of body image: 1. The adjustable body –distorting mirror. *Archives of General Psychiatry, 11*(1), 53-66. doi: 10.1001/archpsyc.1964.01720250055007

Trompeter, N., Bussey, K., Hay, P., Mond, J., Murray, S. B., Longergan, A., Griffiths, S., Pike, K. & Mitchison, D. (2018). Fear of negative evaluation and weight/shape concerns among adolescents: The moderating effects of gender and weight status. *Journal of Youth and Adolescence, 47*(7), 1398-1408. doi: 10.1007/s10964-018-0872-z

Tuschen-Caffier, B., Bender, C., Caffier, D., Klenner, K., Braks, K., & Svaldi, J. (2015). Selective visual attention during mirror exposure in anorexia and bulimia nervosa. *Plos One*, *10*(12), e0145886. doi: 10.1371/journal.pone.0145886

Tylka, T. L. & Wood-Barcalow, N. L. (2015a). What is and what is not positive body image? Conceptual foundations and construct definition. *Body Image, 14*, 118-129. doi: 10.1016/j.bodyim.2015.04.001

Tylka, T. L. & Wood-Barcalow, N. L. (2015b). The Body Appreciation Scale-2: Item refinement and psychometric evaluation. *Body Image, 12*, 53–67. doi: 10.1016/j.bodyim.2014.09.006

Tylka, T. L. (2011). Refinement of the tripartite influence model for men: dual body image pathways to body change behaviours. *Body Image, 8*(3), 199-207. doi: 10.1016/j.bodyim.2011.04.008

Tylka, T. L. & Hill, M. S. (2004). Objectification theory as it relates to disordered eating among college women. *Sex roles, 51*(11-12), 719-730. doi: 10.1007/s11199-004-0721-2

Urvelyte, E., & Perminas, A. (2015). *The Dual Pathway Model of Bulimia: Replication and Extension with Anorexia*. Procedia - Social and Behavioral Sciences, 205, 178–183. doi:10.1016/j.sbspro.2015.09.054

Valente, S., Di Girolamo, G., Forlani, M., Biondini, A., Scudellari, P., De Ronchi, D., & Atti, A. R. (2017). Sex-specific issues in eating disorders: a clinical and psychopathological investigation. *Eating and Weight Disorders - Studies on Anorexia, Bulimia and Obesity, 22*(4), 707–715. doi: 10.1007/s40519-017-0432-7

van der Berg, P., Thompson, K., Obremski-Brandon, K., & Coovert, M. (2002). The Tripartite Influence model of body image and eating disturbance. A covariance structure modelling investigation testing the meditational role of appearance comparison. *Journal of Psychosomatic Research, 53*(5), 1007–1020. doi: 10.1016/s0022-3999(02)00499-3

van Geel, M., Vedder, P., & Tanilon, J. (2014). Are overweight and obese youths more often bullies by their peers? A meta-analysis on the relation between weight status and bullying. *International Journal of Obesity, 38*(10), 1263–1267. doi: 10.1038/ijo.2014.117

Van Hoeken, D., Seidell, J. & Hoek, H. W. (2003). Epidemiology. In Treasure, J. Schmidt, U. & van Furth, E. (Eds.), *Handbook of Eating Disorders* (pp. 11-34). West Sussex: John Wiley & Sons.

Vartanian, L. R., & Dey, S. (2013). Self-concept clarity, thin-ideal internalisation, and appearance-related social comparison as predictors of body dissatisfaction*. Body Image, 10*(4), 495-500. doi: 10.1016/j.bodyim.2013.05.004

de Vignemont, F., & Iannetti, G. D. (2015). How many peripersonal spaces? *Neuropsychologia, 70*, 327–334. doi: 10.1016/j.neuropsychologia.2014.11.018

de Vignemont, F. (2010). Body schema and body image – pros and cons. *Neuropyschologia, 48*(3), 669-680. doi: 10.1016/jneuropsychologia.2009.09.022

De Vignemont, F., Ehrsson, H. H., & Haggard, P. (2005). Bodily Illusions Modulate Tactile Perception. *Current Biology, 15*(14), 1286–1290. doi: 10.1016/j.cub.2005.06.067

Vitousek, K. B. & Hollon, S. D. (1990). The investigation of schematic content and processing in eating disorders. *Cognitive Therapy and Research, 14*(2), 191-214. doi: 10.1007/bf01176209

Vocks, S., Legenbauer, T., Wächter, A., Wucherer, M., & Kosfelder, J. (2007). What happens in the course of body exposure? *Journal of Psychosomatic Research, 62*(2), 231–239. doi: 10.1016/j.jpsychores.2006.08.007

Voracek, M. & Fisher, M. L. (2002). Shapely centrefolds? Temporal change in body measures: trend analysis. *British Medical Journal, 325*(7378), 1447–1448. doi: 10.1136/bmj.325.7378.1447

Walker, D. C., Murray, A. D., Lavender, J. M., & Anderson, D. A. (2012). The direct effects of manipulating body checking in men. *Body Image, 9*(4), 462–468. doi:10.1016/j.bodyim.2012.06.001

Warren, W. H., & Whang, S. (1987). Visual guidance of walking through apertures: body-scaled information for affordances. *Journal of Experimental Psychology*, *13*(3), 371–383. doi: 10.1037/0096-1523.13.3.371

Warren, W. H. & Whang, S. (1987). Visual guidance of walking through apertures: body-scaled information for affordances. *Journal of Experimental Psychology, 13*(3), 371-383. doi: 10.1037/0096-1523.13.3.371

Wells, J. C. K., Griffin, L., & Treleaven, P. (2009). Independent changes in female body shape with parity and age: a life-history approach to female adiposity. *American Journal of Human Biology, 22*(4), 456-462. doi: 10.1002/ajhb.21017

Wells, J. C. K., Cole, T. J., Bruner, D., & Treleaven, P. (2008). Body shape in American and British adults: between-country and inter-ethnic comparisons. *International Journal of Obesity, 32*(1), 152-159. doi: 10.1038/sj.ijo.0803685

Wells, J. C., Treleaven, P., & Cole, T. J. (2007). BMI compared with 3-dimensional body shape: the UK national sizing survey. *The American Journal of Clinical Nutrition, 85*(2), 419–425. doi: 10.1093/ajcn/85.2.419

Wertheim, E. H., Paxton, S. J., Schutz, H. K., & Muir, S. L. (1997). Why do adolescent girls watch their weight? An interview study examining socio-cultural pressures to be thin. *Journal of Psychosomatic Research, 42*(4), 345-355. doi: 10.1016/s0022-3999(96)00368-6

Wildes, J. E., Emery, R. E., & Simons, A. D. (2001). The roles of ethnicity and culture in the development of eating disturbance and body dissatisfaction: A meta-analytic review. *Clinical Psychology Review, 21*(4), 521-551. doi: 10.1016/s0272-7358(99)00071-9

Wilksch, S. M., Tiggemann, M., & Wade, T. D. (2006). Impact of interactive school-based media literacy lessons for reducing internalisation of media ideals in young adolescent girls and boys. *International Journal of Eating Disorders, 39*(5), 385-393. doi: 10.1002/eat.20237

Williamson, D. A., White, M. A., York-Crowe, E., Stewart, T. M. (2004). Cognitive-behavioral theories of eating disorders. *Behaviour Modification, 28*(6), 711-738. doi: 10.1177/0145445503259853

Williamson, D. A., Muller, S. L., Reas, D. L., & Thaw, J. M. (1999). Cognitive Bias in Eating Disorders: *Behavior Modification, 23*(4), 556–577. doi:10.1177/0145445599234003

Williamson, D. A. (1996). Body image disturbance in eating disorders: A form of cognitive bias? *Eating Disorders: The Journal of Treatment and Prevention, 4*(1), 47-58. doi: 10.1080/10640269608250075

Winchester, E. & Collier, D. (2003) Genetic aetiology of eating disorders and obesity. In Treasure, J. Schmidt, U. & van Furth, E. (Eds.), *Handbook of Eating Disorders* (pp. 35-62). West Sussex: John Wiley & Sons.

Winkler, C. & Rhodes, G. (2005). Perceptual adaptation affects attractiveness of female bodies. *British Journal of Psychology, 96*(2), 141-154. doi: 10.1348/000712605x36343

Winzberg, A. J., Eppstein, D., Eldredge, K. L., Wilfley, D., Dashmahapatra, R., Dev, P., & Taylor, C. M. (2000). Effectiveness of an internet-based program for reducing risk factors for eating disorders. *Journal of Consulting and Clinical Psychology, 68*(2), 346-350. doi: 10.1037/0022-006x.68.2.346

Witmer, B. G & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and Virtual Environments, 7*(3), 225-240. doi: 10.1162/105474698565686

World Health Organisation (2003). Shaping the future report. Retrieved from http://www.who.int/whr/2003/en

Woo, C. W., Roy, M., Buhle, J. T., Wager, T. D. (2015). Distinct brain systems mediate the effects of nociceptive input and self-regulation on pain. *PLOS Biology, 13*(1), e1002036. doi: 10.1371/journal.pbio.1002036

Zabinski, M. F., Wilfley, D. E., Calfas, K. J., Winzerlberg, A. J., & Taylor, C. B. (2004). An interactive psychoeducational intervention for women at risk of developing an eating disorder. *Journal of Consulting and Clinical Psychology, 72*(5), 914-919. doi: 10.1037/0022-006x.72.5.914

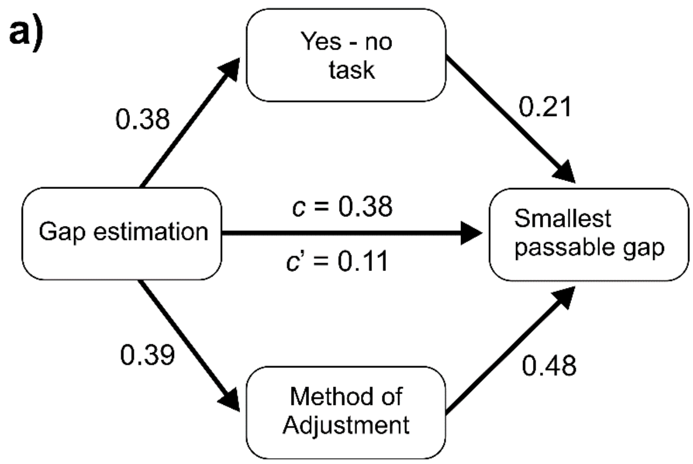
Zeman, A., Dewar, M., & Della Sala, S. (2015a). Lives without imagery – Congenital aphantasia. *Cortex, 73*, 378–380. doi: 10.1016/j.cortex.2015.05.019

Zeman, A., Dewar, M., & Della Sala, S. (2015b). Reflection on aphantasia. *Cortex, 74*, 336–337. doi: 10.1016/j.cortex.2015.08.015

Zucker, N.L., Merwin, R.M., Bulik, C.M., Moskovich, A., Wildes, J., & Groh J. (2013). Subjective experience of sensation in anorexia nervosa. *Behaviour Research and Therapy, 51(6),* 256-265. doi: 10.1016/j.brat.2013.01.010

Appendix A

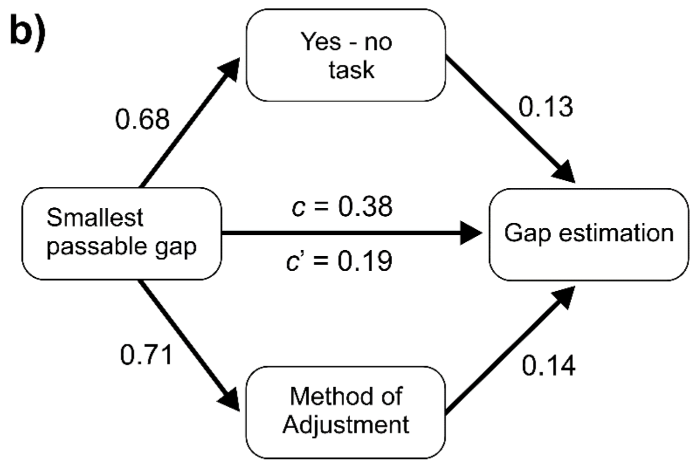
Figure a) below illustrates the model in Fig. 3.1 which was tested first for mediation alone with both the yes-no task and MoA as mediators. It is compared with Figure b) which has the same number of paths, but the positions of gap estimation and smallest passable gap are swapped around.



Mean bootstrapped indirect effect:

0.27 95%CI (0.12 - 0.40)

Model $R^2 = 0.53$



Mean bootstrapped indirect effect:

0.19 95%CI (-0.03 - 0.41)

Model $R^2 = 0.18$

Appendix B

Figures below illustrate the model in Fig. 3.1 while substituting participants' gap estimation based on their own body for a control object – yoga ball. No significant mediation effects were shown suggesting that medciation effects observed were specific to body representations.