Abstract

Our body is omnipresent in our perceptual experience and is central to what we define as our *self*. We can feel our body, touch it, see it, act with it, and we can reflect cognitively on it. How we mentally represent our bodily appearance can have a great influence on our psychological health. The role of perceptual and cognitive factors and specific characteristics of visual body representations are however still unclear. Given the increasing body mass index worldwide and the societal pressure to conform to body ideals, it is important to gain a better understanding of body representations and factors that play a role in visual body size estimation in non-clinical populations. The aim of this doctoral thesis was to advance our theoretical understanding of visual body representations by extending on existing literature in important and novel ways. A **multifaceted approach** was taken for investigating **body size estimation** by using a variety of experimental methods and novel state-of-the-art computer graphics methods for generation of biometrically plausible virtual bodies. The ability to realistically manipulate individual body shape and appearance features of the virtual bodies based on statistical body models and 3D body scans was utilized to investigate the role of different visual cues in the estimation of own body size and shape. Two visual cues were considered, **visual perspective**, and **identity cues in the visual appearance of the body**. The novelty of this lies in the multi-disciplinary iterative approach of designing technology to meet the requirements of experimental methods and statistical analyses. Another novelty regards the investigation of interactions of the role of visual cues in body size estimation with **self-specific factors** by recruiting participant populations varying in body size and gender. **High ecological validity** was achieved by testing body size estimation in a natural setting, when viewing oneself in a mirror and when looking down (Chapter 1), and by simulating real-world scenarios in immersive virtual reality (Chapter 2, 3, 4, and Appendix A, B, and C). Chapter 1 and 2 cover experiments that investigate the role of visual information and perspective in the estimation of own body part dimensions and body weight. The influence of viewing condition was investigated in a **real-world scenario** using a metric body size estimation task in Chapter 1, and in a depictive body size estimation task in **immersive virtual reality** in Chapter 2, where parameters of a gender-matched virtual body could individually be adjusted. The experiments presented in Chapter 3 examine potential gender differences in the importance of identity cues in the visual appearance of a body (shape, color-information) for body size estimation. The aim of Chapter 4 was to investigate whether variability in the accuracy of body size estimates of self and others can partially be accounted for by own body size itself by testing females spanning the body mass index range from underweight to obese. The experiments presented in the Appendices cover follow-up studies on the chapters. This doctoral thesis provides novel insights into the role of visual cues in body size estimation, with a focus on visual perspective and identity cues in the visual appearance of a body, and their interactions with self-specific factors. The studies revealed that the effect of visual perspective on body size estimation is both task- and gender-specific. The role of identity cues in the visual appearance of the body stimuli was dependent on the participant population for body size estimates, and showed clear gender differences with regard to the evaluation of the virtual body's appearance. This work suggests that more attention should be given to the effect of task characteristics on the outcome of body size estimation tasks, as well as their interactions with self-specific factors, in terms of the type of body representation that is assessed and the interpretation and comparability of the results across studies.

Aim and Structure of the Thesis

The aim of this doctoral thesis is to gain a better understanding of **the role of visual cues in body size estimation** in non-clinical populations of males and females by taking a multifaceted approach. Data was gathered both in a natural setting, when looking down at one's body or seeing it in a full-length mirror (Chapter 1), and in ecologically valid scenarios in immersive virtual reality (Chapter 2, 3, and 4, and Appendix A, B, and C). State-of-the-art immersive virtual reality (VR) display technologies were utilized to simulate real-world situations and to systematically manipulate and investigate the role of different visual cues (**visual perspective**, and **identity cues**) in BSE, in ways not possible in the real world. To overcome methodological issues of previous studies, a novel computer graphics method was used that allows for generation of realistic 3D virtual bodies based on statistical body models and 3D body scans. This method allows for manipulations of the degree of individual body shape and appearance features as well as bodily dimensions in biometrically plausible ways. BSE was investigated by embedding the virtual bodies into well-established psychophysical methods. High ecological validity was achieved by presenting the body stimuli in life-size in immersive virtual reality set-ups, mimicking scenarios as if looking down at one's body, standing in front of a full-length mirror, or facing another person. The motivation and importance for investigating the role of visual perspective and identity cues in BSE, as well as their interactions with own body size and gender, is outlined in the following paragraphs.

Motivation and Overview

There are two **visual perspectives** we have on our bodies in daily life. We can visually experience our bodies from a first-person perspective, when looking down at the body, and from a third-person perspective, in mirrors or other reflective surfaces, or in pictures. While the first-person perspective is unique to our own body, the third-person perspective is the view we also have on other people's bodies. Self-other comparisons of bodily appearance might rely on a common reference frame and thus a literal "body image" of oneself. However, the amount of time spent viewing oneself in full-length mirrors is, for most healthy people, relatively limited as compared to the duration and frequency of visual exposure to own body size and shape from a first-person perspective during the day, when performing actions or looking down. Previous research has presented inconclusive results as to whether estimates with visual feedback of the body are more accurate than without visual feedback (Ben-Tovim & Walker, 1990; Docteur, Urdapilleta, & Duarte, 2012; Farrell, Shafran, & Fairburn, 2003; Gardner, Gallegos, Martinez, & Espinoza, 1989; Øverås, Kapstad, Brunborg, Landrø, & Lask, 2014; Shafran & Fairburn, 2002). None of these studies has related estimates of body size with visual feedback available in a mirror to those with visual feedback from a first-person perspective and those without visual access to the body. **Chapter 1** investigated which visual information might predominantly be used to form people's mental representation of their body dimensions, by comparing estimates of body widths without visual access to the body, as it is usually the case in BSE tasks, to estimates with visual feedback available from a first- and third-person perspective. In a real-world setting, participants estimated the width of their foot, hips, shoulders, and head in a metric BSE task by verbally instructing the experimenter to adjust a tape measure. **Chapter 2** extended on this by investigating the ability to estimate own body weight and shape from a first- and third-person perspective. Participants adjusted various parameters of a virtual body that was either co-located with the participant's position in an head-mounted display (HMD)-based immersive virtual environment and was visible when looking down, or was standing in front of the participant and was being viewed from a third-person perspective. The implementation of this depictive BSE task allowed to not only assess the estimation of single body dimensions, as in a metric BSE task, but the estimation of overall body size and shape because direct visual feedback of the estimates was available in the virtual body.

In these first two studies, as well as in the literature, **identity cues of the body** were not systematically varied. However, there are many ways how we can evaluate our body. The full view of our body in a mirror can reveal weight gain or loss, and the comparison of own body size to others provides information about our body relative to, for example, what we desire, or what the average is. Though different mechanisms might underlie these two types of body size judgments, previous research has given little consideration to identity cues in the visual appearance of the body stimuli in depictive BSE tasks. Studies have either used personalized body stimuli created based on depictions of the participants (e.g., Hagman et al., 2015; McCabe et al., 2006; Urdapilleta et al., 2007), or non-personalized body stimuli based on the same standard body (e.g., K. K. Cornelissen et al., 2015; K. K. Cornelissen, Cornelissen, Hancock, & Tovée, 2016). The outcome of those studies has generally been interpreted in the same way, namely in terms of how accurately people perceive their own body size. However, there are several important differences between those two types of body stimuli, in terms of the available cues that might inform body size estimates. Estimates made relative to depictions of own body weight variations could be based on body proportions or a direct mental mapping of own shape onto the stimuli. Such self-self comparisons might also be more susceptible to influences of self-specific conceptual body representations. When judging own body size against another body (self-other judgments), the shape of the body stimuli is not directly informative, so the estimates have to be based more holistically on the body weight or other dimensions, or the weight category. As body shape variations across participants are not captured in non-personalized body stimuli, relying on body shape cues would give rise to body-shape dependent variability across participants, with more accurate body size estimates for individuals with similar body shapes as the body stimuli. A recently published study suggests that task characteristics might cause observers to use different references in BSE tasks – the distribution of body sizes in the population, or their own body – and this could bias the accuracy of BSE in one case, but not the other (K. K. Cornelissen et al., 2017). This could similarly be the case depending on whether cues for own identity are present or absent in the body stimuli.

The role of **identity cues** in the visual appearance of the body stimuli in BSE was investigated across several studies presented in this doctoral thesis (**Chapter 2, 3, and 4, and Appendix A, B, and C**), by using novel computer graphics methods for creation of realistic 3D virtual bodies with varying degrees of individual body shape and appearance features. Importantly, the common topology of the virtual bodies allowed a decoupling of body shape and color-related body appearance (body texture). Personalized virtual bodies (avatars) with own shape and photo-realistic texture were generated based on individual 3D body scans, and were realistically manipulated in body weight using a statistical body model (Hirshberg, Loper, Rachlin, & Black, 2012) for the experiments presented in Chapter 3 and 4. In **Chapter 3**, the relative importance of body shape (own, other) and texture (own photo-realistic, checkerboard) in BSE was investigated. This was achieved by creating a set of semi-personalized body stimuli with an underlying average body shape matched to each participant's height and weight, in addition to the set of personalized body stimuli. The importance of body texture (color-information) was examined by comparing BSE when own photo-realistic texture, or a checkerboard texture that masks low-level identity features, was applied to the bodies. With the same approach, the role of color-information (own photo-realistic texture, grey texture) in body weight and shape estimation was investigated in **Chapter 2**. The ability to swap the virtual body's identity by applying another person's photo-realistic texture was utilized in **Chapter 4** to investigate whether similar biases underlie the estimation of own body size and the body size of a previously memorized body with other identity. The rational behind using body stimuli with the same underlying body shape, but different identities to investigate BSE of self and others, was to control for body shape differences and the amount of visual exposure to the body shape, due to the relevance of shape cues for BSE. Extending on Chapter 4, BSE was investigated using non-personalized body stimuli spanning the BMI range in **Appendix A**. Semi-personalized body stimuli based on hand measurements of height, weight, arm span, and leg length were used in **Appendix B and C** to investigate the effect of viewpoint on BSE and potential differences in own weight estimates relative to a same- and opposite-sex body. The generation of body stimuli matched in specific body dimensions to each participant is much quicker and easier as compared to 3D body scans, but at the same time controls for body-shape dependent variability in BSE across participants due to the degree of similarity of own body dimensions to the stimuli.

Finally, an important aspect to consider is how **self-specific factors** of the participants interact with the role of visual cues in BSE. Two factors were considered in this doctoral thesis: own body size, and gender. Little research has examined BSE in males and potential **gender differences** (Gardner, 2014). The majority of research has focused on BSE in females due to the higher prevalence of eating disorders and the role of body image disturbances in these disorders. Though the cultural body ideals for men and women are linked to different bodily aspects, muscularity for males and weight for females, few studies have looked at whether males and females show differences in their ability to estimate own body dimensions. In **Chapter 2**, potential gender differences in the estimation of body weight and other dimensions (arm span, leg length, hip width, and arm length) that potentially vary in importance for males and females, and their interaction with visual perspective on the body was examined. Visual perspective might have a gender-specific effect on BSE, because different body parts are more or less visible from a first-person perspective. In **Chapter 3**, the relative importance of identity cues for the estimation of own body weight, the sensitivity to weight changes, and the evaluation of the appearance similarity of the virtual bodies was investigated in males and females.

Another factor that could interact with the role of visual cues in BSE is **personal body size**. There has been a growing interest in the role of own body size in body image disturbances, due to the significant increase of the mean BMI in the last decades and the rising prevalence of obesity worldwide (NCD Risk Factor Collaboration, 2016). Obesity (BMI $\geq$ 30) is a major public health problems (Ferrari et al., 2013; World

Health Organisation, 2018) and a risk factor for the development of a variety of chronic diseases (Flegal, Kit, Orpana, & Graubard, 2013; Grover et al., 2015), as well as affects psychological well-being (Luppino et al., 2010; Wardle & Cooke, 2005). So far, studies have presented inconclusive results as to whether individuals with overweight (BMI 25–29.9) and obesity have a disturbed ability to accurately identify own weight and changes in own weight (Gardner, 2014; Polivy, Herman, & Pliner, 1990). Recent research suggests that misestimations of own body size may occur due to a bias in BSE towards the average body size in the environment by an error in magnitude estimation called *contraction bias* (K. K. Cornelissen et al., 2015; K. K. Cornelissen, Gledhill, Cornelissen, & Tovée, 2016). As yet, the circumstances under which such a bias might occur in estimates of own body size are unknown. Understanding the role of weight status in the estimation of own body size is important because a distorted perception of own body size may be a predictive factor for overweight and obesity, and may be involved in the development and maintenance of eating disorders (J. K. Thompson, 1996). In **Chapter 4** and **Appendix A**, non-clinical populations of females spanning the BMI range from underweight to obese were recruited to test whether own body size predicts the accuracy of BSE and the sensitivity to weight changes when personalized and non-personalized body stimuli are used. Experimental data was combined with self-report instruments, as certain psychometric variables are likely to co-vary with own body size and gender, such as self-esteem, eating behaviour, emotional self-evaluation, and attitudes towards own body size and shape.

Overview of the Chapters

This doctoral thesis comprises four main chapters that are, at the time of the thesis submission, either published in peer-reviewed journals (Chapter 1, 3, and 4), or prepared for publication (Chapter 2).[2] Additional experiments that have not been prepared for publication yet, are presented in the Appendices. In total, the experiments present data of 190 female and 60 male participants.

- Chapter 1: **Thaler A**, Geuss MN, and Mohler BJ (2018). The Role of Visual Information in Body Size Estimation. *iPerception*, 9(5), 1-16.

- Chapter 2: **Thaler A**, Pujades S, Stefanucci JK, Creem-Regehr SH, Tesch J, Black MJ, and Mohler BJ (2019). The Influence of Visual Perspective on Body Size

[2] The manuscript in Chapter 2 got published after the thesis submission. For the published doctoral thesis, the manuscript in preparation was replaced by the published manuscript.

Estimation in Immersive Virtual Reality. In *Proceedings of the ACM Symposium on Applied Perception 2019*, Article No. 5.[2] [Appendix B covers a related experiment.]

- Chapter 3: **Thaler A**, Piryankova I, Stefanucci JK, Pujades S, de la Rosa S, Streuber S, Romero J, Black MJ, and Mohler BJ (2018). Visual Perception and Evaluation of Photo-Realistic Self-Avatars From 3D Body Scans in Males and Females. *Frontiers in ICT: Virtual Environments*, 5:18. [Appendix C covers a related experiment.]

- Chapter 4: **Thaler A**, Geuss MN, Mölbert SC, Giel KE, Streuber S, Romero J, Black MJ, and Mohler BJ (2018). Body Size Estimation of Self and Others in Females Varying in BMI. *PLoS ONE*, 13(2): e0192152. [Appendix A covers a related experiment.]

- Appendices: Appendix A: Estimation of Own, Ideal, and Average BMI; Appendix B: Is Body Size Estimation Viewpoint Invariant?; Appendix C: Can Females Estimate Their Weight on a Male Body?; Appendix D: Biometric Figure Rating Scales.

Chapter 1: The Role of Visual Information in Body Size Estimation

Research Aim: The aim of Chapter 1 was to investigate whether different visual experiences of one's own body influence BSE. Width estimates of single body parts without visual access to the physical body were compared to estimates when visual feedback was available in a mirror or from a first-person perspective. The rational behind comparing BSE across these conditions was to test if estimates of own body size without visual access are more similar to those made when seeing one's body in a mirror as compared to the first-person perspective. This would suggest that the mental representation of bodily dimensions might partially be influenced by visually experiencing one's body from a third-person perspective.

Methods: A real-world scenario and a metric BSE task were used where participants estimated the width of different body parts by verbally instructing the experimenter to adjust the length of a tape measure. A between-subjects design was employed to prevent carry-over effects across conditions. In Experiment 1, width estimates of three body parts (foot, hips, and shoulders) without visual access to the body were compared to estimates with visual feedback available in a full-length mirror or from a first-person perspective. In the no visual access and mirror condition, participants additionally estimated their head width. After the experiment, participants' actual body dimensions were measured using a tape measure. To control for the possibility that inaccurate body width estimates were be due to the metric BSE task or the experimental conditions themselves, Experiment 2 tested size estimation of unfamiliar non-corporeal objects using the same task and similar viewing conditions. Participants estimated the size of stripes of paper placed at the height of the same body parts as in Experiment 1, either when viewing the objects in a mirror or when directly looking at the objects.

Results: There was no influence of viewing condition on body part width estimates in Experiment 1. Consistent with previous research, all body part widths were overestimated, with 6% overestimation of the foot, 23% of the hips, 13% of the shoulders, and 31% of the head. In Experiment 2, the width of objects placed at foot and hip height was accurately estimated in both conditions, whereas with visual feedback in a mirror available, the width of objects placed at shoulder and head height was overestimated by around 14% and 13%. While it is unclear what led to the overestimation of object widths placed at the height of the shoulders and the head when viewed in the mirror, the results suggest that dimensions are not generally overestimated in a metric BSE task. At least some of the overestimation of body part width seems to be body-specific and occurs regardless of the visual information provided about the own body. A possible interpretation of these results is, that people use a common body representation when estimating own body dimensions under different viewing conditions and without visual access to the body in a metric BSE task. Indeed, some previous literature suggests that metric BSE tasks might not only assess explicit knowledge of own body size, but also recruit implicit body representations that rely on proprioception and somatosensation and that are characterized by systematic width overestimations (Longo & Haggard, 2010; Mölbert, Klein, et al., 2017).

Chapter 2: The Influence of Visual Perspective on Body Size Estimation in Immersive Virtual Reality

Research Aim: The aim of Chapter 2 was to investigate the influence of visual perspective (first-person and third-person perspective) on body weight and shape estimation in a depictive BSE task, and potential gender differences in these estimates. Although there is agreement on the importance of visual information for depictive BSE tasks, previous studies have only looked at estimates made by comparing own body size to test bodies viewed from a third-person perspective. However, in daily life, the amount of time spent seeing one's own body from a third-person perspective is relatively little as compared to the time one's own body dimensions are visually experienced from a first-person perspective. Furthermore, most previous studies have focused on the estimation of body weight, only few studies have investigated shape estimation where participants could individually adjust the size of different parts of the body stimuli (e.g., Tovée et al., 2003). Since the importance of different body dimensions might differ for males and females, visual perspective could have a gender-specific effect on BSE, as certain body parts are more or less visible from a first-person perspective.

Methods: A novel avatar creation tool (*The Virtual Caliper*) was used that allows for independent manipulations of body weight and single body part dimensions of a virtual body (including arm span, leg length, hip width, and arm length) in biometrically plausible ways based on a statistical body model (Pujades et al., 2019). Participants' body dimensions were measured in session 1 and for a subset of the participants a 3D body scan was collected using a full-body scanning system. In session 2, a gender-matched virtual body with grey texture was presented in life-size in immersive virtual reality either co-located with the participant or facing the participant from a distance of two meters in an HTC Vive HMD. The height of the body was set to each participant's body height to prevent the need for re-scaling the estimates and because deviations in height between the participant and the avatar would have resulted in an unrealistic first-person perspective on the body. The dimensions of the initial avatar in each trial were calculated based on the individual anthropometric measurements to present participants with bodies bigger and smaller than themselves. In a MoA task, participants adjusted the dimensions of the virtual body to match their own by moving sliders on a virtual interface using the controller of the HTC Vive. In the different trial types, one (weight), three (weight, arm span, and leg length), or five (weight, arm span, leg length, hip width, and arm length) parameters of the virtual body could be adjusted. The subset of the participants that got a body scan additionally completed one block of trials where their own photo-realistic texture was applied to the body, to investigate the influence of identity cues on BSE. Post-questionnaires were used to assess participants' perceived similarity of the virtual body to their own body.

Results: In trials where participants could adjust only the weight of the virtual body, both males and females underestimated their own weight. There was no gender difference in the accuracy of estimated own weight when the body was viewed from a third-person perspective (10% underestimation). However, males underestimated their weight more (18% underestimation) when viewing the body from a first-person perspective, whereas visual perspective did not have an influence for females. This gender-specific effect of visual perspective on body weight estimates was dependent on the trial type, and thereby the amount of control over the body shape, indicating that the results might be caused by where in the virtual body the weight changes expressed themselves. Both males and females underestimated their weight more when the photo-realistic texture was applied to the virtual body as compared to the grey texture. This could either be due to shape from shading cues in the photo-realistic textures, or from identifying more with the body as the post-questionnaires revealed. There were some effects of visual perspective on the accuracy of estimated body part dimensions, potentially due to differences in the visibility of the body parts caused by i.a., the restricted field of view of the HMD. The estimates were however relatively accurate and within a range of ±6%. Compared to Chapter 1 (Thaler, Geuss, & Mohler, 2018), this result suggests that when direct visual feedback of the body part size estimates is available (in the virtual body), the task might assess a more explicit body representation, that does not show large systematic distortions as previously found in tasks that presumably assess implicit representations.

Note: The most common third-person perspective view on one's own body is the front view. However, in daily life, people constantly see and compare themselves to other people's bodies in different viewpoints. The influence of viewpoint of the body stimuli on the estimation of own body size was explored in the study presented in **Appendix B**.

Chapter 3: Visual Perception and Evaluation of Photo-Realistic Self-Avatars from 3D Body Scans in Males and Females

Research Aim: The aim of Chapter 3 was to investigate potential gender differences in the relative importance of identity cues in the visual appearance of a body (shape and texture) for the estimation of own weight, the sensitivity to weight changes, and the desired body weight. Previous studies on BSE have either used non-personalized body stimuli (e.g., K. K. Cornelissen et al., 2015; K. K. Cornelissen, Cornelissen, et al., 2016) or personalized body stimuli (e.g., Urdapilleta et al., 2007), where in both cases body shape and color-related body appearance are coupled. Piryankova et al. (2014) were the first to investigate the influence of body shape and texture on BSE in females. Little research has investigated BSE in males in the normal weight range (Gardner, 2014), and potential gender differences in the importance of different identity cues in the visual appearance of the body stimuli for BSE. Chapter 3 covers four sets of psychophysical experiments that investigate gender differences in BSE using systematically manipulated body stimuli, by comparing the data of thirteen males to the data of thirteen females that was partially published in Piryankova et al. (2014).

Methods: A full-body scanning system was used to capture each participant's body geometry and color information, and a set of personalized 3D bodies (avatars) with realistic variations of body weight was created based on a statistical body model (Hirshberg et al., 2012). In addition, another set of body stimuli was created for each participant, with an underlying average body shape matched to the participant's height and the weight variations of the set of personalized body stimuli. The influence of color-information (texture) of the body on BSE was investigated by applying participants' own photo-realistic textures to the bodies, or a checkerboard texture. In the checkerboard texture, any color-details specific to the participant and low-level visual features of the body was removed, thereby drawing attention to the overall body shape. A depictive BSE task was used, where the body stimuli were presented in life-size on a large-screen immersive display. In four sets of two psychophysical experiments (1AFC and MoA), the influence of visual identity cues on the accuracy of BSE and the sensitivity to weight changes was assessed by manipulating body shape (own, average) and texture (own photo-realistic, checkerboard). In a 1AFC task, participants were presented with the distinct weight variations of the body stimuli set and responded to whether the body corresponded to their own weight, or they adjusted the body weight to match their own and their desired weight in a MoA task. In addition, given the growing interest in creation and streaming of self-avatars in applications related to embodied VR, telepresence, and immersive games, computer-graphics-relevant questionnaires were administered. The questionnaires were used to assess the importance of identity cues for the evaluation of avatar appearance in terms of similarity to participants' own bodies, uncanniness, and the willingness to accept the virtual bodies as a digital representation of the self.

Results: There was no gender difference in the influence of body shape and texture on BSE. Males and females slightly underestimated their body weight in the 1AFC task and accurately estimated their weight in the MoA task, both for own and average shape. These results suggest that males and females in the normal weight range are able to estimate their weight on bodies with their own height, but a different body shape. The difference in results between the two psychophysical methods could be due to the finer step size in the MoA task that allows for more precise adjustments. Accurate weight estimation or slight weight underestimation is in line with the results of females in the normal weight range in Mölbert et al. (2018) and in Chapter 4 (Thaler, Geuss, Mölbert, et al., 2018). The body shape details available in 3D body scans might explain the difference in results compared to Chapter 2 (Thaler et al., 2019), where a statistical body model with smooth body surface was used. Participants responded that a body with a significantly lower body weight corresponded to their actual weight for the checkerboard texture as compared to their own photo-realistic texture. The textures differ in multiple aspects that could explain this result. The photo-realistic texture contains lighting information from the body scan and provides shape from shading information, whereas the checkerboard texture has no directional lighting information. They further clearly differed in their human-like appearance. Indeed, the results of the post-questionnaire similarity ratings revealed that participants generally felt the bodies with the checkerboard texture were less similar to themselves. There was a gender difference in the sensitivity to weight changes, males accepted a larger weight range as corresponding to their own weight than females. In terms of the ideal body weight, females but not males desired a thinner body than their actual body. The higher sensitivity to weight changes and the wish to be thinner in females, is in line with body weight being a central aspect of body dissatisfaction (Feingold & Mazzella, 1998). Males might be less concerned about their weight, but other bodily aspect that could not be manipulated in this study, such as muscularity or height. Although no gender difference was found in the influence of body shape and texture on the accuracy of BSE and the sensitivity to weight changes, males rated the virtual bodies to be more similar to themselves when their own photo-realistic texture was shown, independent of whether the underlying body shape was their own or not. Females on the other hand rated the virtual bodies with their own shape as more similar to their own body, whereas the texture was not that important. These results argue for gender-specific considerations when creating self-avatars for VR applications.

Note: The bodies with underlying average body shape matched to each participant's height and weight might still be relatively similar in shape to participants' actual body. **Appendix C** extends on this by testing whether females are also able to estimate their weight on a male body that clearly differs from a female body, both in shape and texture, and in the way that weight changes express themselves based on a gender-specific statistical body model (Hirshberg et al., 2012).

Chapter 4: Body Size Estimation of Self and Others in Females Varying in BMI

Research Aim: The aim of Chapter 4 was to investigate whether own body size, indexed by BMI, predicts the accuracy of BSE and the sensitivity to weight changes of self and others in a non-clinical population of females spanning the BMI range from underweight to obese. Previous studies have suggested that inaccurate estimates of own body size might be a secondary effect of the body size itself and that estimates are biased towards the average body size in the population (K. K. Cornelissen et al., 2015; K. K. Cornelissen, Gledhill, et al., 2016). A *contraction bias* predicts that the size of low BMI bodies is overestimated and the size of high BMI bodies is underestimated. Although previous studies assume that similar biases might underlie BSE of self and others, none of the studies has systematically investigated this. Chapter 4 covers three experiments that systematically investigate BSE of self and others in females varying in BMI.

Methods: The body stimuli were generated based on individual 3D body scans and a statistical body model that is able to model realistic weight gain and weight loss (Hirshberg et al., 2012). An immersive virtual reality back-projection set-up was used to mimic a scenario of standing in front of a full-length mirror or a life-size person. Fifty-four female participants spanning the BMI range from underweight to obese, with no current or past eating or other psychiatric disorders, were recruited for the study. A depictive BSE task and two psychophysical methods, a 1AFC and a MoA task, were used to assess the accuracy of BSE and the sensitivity to weight changes. In Experiment 1, participants estimated their own body size by comparing themselves to their personalized body stimuli (avatars). In Experiment 2a, participants estimated the size of a previously memorized body with another identity. The identity of the body stimuli was manipulated by swapping participants' own photo-realistic textures for the photo-realistic texture of another person. Keeping the same underlying body shape allowed to control for body shape differences between self and others and the exposure to the body shape. In Experiment 2b, participants estimated the size of their own previously memorized body to control for differences in the experimental design between Experiment 1 and 2a. Cognitive-affective body-related factors were assessed by administering several validated questionnaires, and letting participants adjust the weight of their personalized avatar to match their desired weight.

Results: The results of Experiment 1 showed that the accuracy of self-BSE was predicted by own BMI. In contrast to what a *contraction bias* would predict, participants with a lower BMI underestimated their body size and participants with a higher BMI overestimated their body size. Further, participants with a higher BMI were less likely to notice the same percentage of weight gain than females with a lower BMI. Accounting for differences in psychometric variables as assessed by the questionnaires did not change the results. Importantly, these results were only apparent when participants estimated their body size on a virtual body with their own identity (Experiment 1), but not when they estimated the size of a previously memorized body with another identity but the same underlying body shape (Experiment 2a). When participants estimated the size of their own body after being exposed to it (Experiment 2b), own BMI did not predict the accuracy of estimated own body size. This was similar to the results of Experiment 2a, but sensitivity to weight gain decreased with increasing BMI as in Experiment 1. The results show that participants were generally able to memorize and estimate the size of a body with their own weight and shape. Furthermore, the effect of BMI on the sensitivity to weight gain only occurred when participants judged the size of a body with their own identity. Although cognitive-affective factors could not explain the influence of own BMI on BSE of self, the results suggest that estimates of own body size and the sensitivity to weight changes might be affected by non-visual factors that are self-specific. Females across the BMI range desired a thinner body, with a growing discrepancy between the desired and actual body weight with increasing own BMI.

Note: Besides viewing oneself in a mirror, another way of evaluating own body size is by comparison to others' bodies. **Appendix A** extends on Chapter 4 by testing whether personal BMI also predicts the accuracy of estimated own body size and the desired body size in females spanning the BMI range, when non-personalized body stimuli with an underlying average body shape are presented.

General Discussion

The aim of this doctoral thesis was to gain a better understanding of the role of different **visual cues in BSE** in non-clinical populations by taking a multifaceted approach, focusing on the role of **visual perspective** and **identity cues** in the visual appearance of a body in BSE, and their interactions with own body size and gender. The main contribution of this doctoral thesis to the existing literature is the systematic investigation of theses factors across various experiments both in a real-world scenario and