An investigation of perceptual factors that influence body size estimation errors

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Bachelor of Arts (Double Major in Psychology) (Honours)

This thesis is presented for the degree of

Doctor of Philosophy of the University of Western Australia

School of Psychological Science

November 2019
Thesis Declaration

I, Joanna Alexi, certify that:

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Erring in our estimation of body size is common but individuals with eating disorders show greater body size misperceptions than typical observers. These misperceptions have been linked to body image disturbances, a core criteria for diagnosis of anorexia nervosa and a known clinical feature of other subtypes of eating disorders. Since bodies are visual objects, it is important to consider the perceptual factors that contribute to body size misperceptions. The overall goal of this thesis is to provide insight into the perceptual mechanisms contributing to body image disturbances. A small set of perceptual factors have already been identified. For instance, regression to the mean bias and adaptation aftereffects have both been shown to contribute to body size misperception. More recently, a novel phenomenon of perceptual bias was discovered, termed serial dependence. To date, it is unknown whether this form of bias contributes to body size misperception, and if it does, whether the bias is clinically relevant. This represents the first aim and section of this thesis.

Serial dependence occurs when perceptual judgments are biased towards recently viewed stimuli. This bias has been observed for a range of visual stimuli, but not yet for body size. Study 1 developed a novel paradigm that could measure serial dependence, which we term the *bodyline task*. The procedure additionally permitted calculation of regression to the mean bias. Hence, this allowed for the consideration of how perceptual biases might interact. Study 1 revealed that serial dependence does occur in the estimation of body size. Interestingly, we found that serial dependence and regression to the mean were unrelated. Next, we sought to determine if serial dependence was related to eating disorder symptomatology, i.e., clinically relevant. Study 2 did indeed find that the magnitude of serial dependence bias was positively and significantly related to eating disorder symptoms in young
women. This association is discussed within the theories of weak central coherence and cognitive inflexibility.

Having developed a novel paradigm for investigating body size estimation and the factors contributing to error, the second major aim and section of this thesis sought to examine how robust these findings are to different experimental circumstances that are employed within the literature. Computer generated (CG) software has allowed significant advances in the representation of bodies, offering parametric control over attributes and the opportunity for dynamic movement. However, there is a dearth of literature describing the consequences of shifting from real to CG body imagery, nor of the impact of adding dynamic movements to the to-be-judged body.

Accordingly, Study 3 investigated whether CG body stimuli can be used interchangeably with real body images or, whether key visual features (e.g. visible emaciation or cellulite), may become perceptually compromised by CG algorithms. Results indicated that judgments of CG bodies were non-linear and increased body size misperceptions, owing to serial dependence. These findings suggest that CG bodies may be judged differently than real bodies; though technological advances may alter this in the future.

Finally, Study 4 investigated whether body size estimations and associated perceptual biases, are robust under dynamic conditions, such as when the to-be-judged body appears to move away from the observer. The results revealed that body size representations were systematically biased under dynamic conditions. Interestingly, the dynamic condition showed increased regression to the mean and serial dependence biases. The latter finding is discussed with reference to consequences of altering stimulus uncertainty. The results of Studies 3 and 4
suggested that changes to visual cues through the use of CG bodies or changes to the retinal size of an image, alters body size representation and increases body size misperceptions.

In summary, the first section of this thesis reveals a causal factor in body size misperceptions, serial dependence, and demonstrates its clinical relevance. The second section demonstrates the volatility of size estimates under different experimental conditions, suggesting caution in the transition towards synthetic imagery and dynamic environments. Collectively, the findings presented in this thesis have important implications for (1) understanding the nature and extent of perceptual body image disturbances in an eating disorders context, (2) providing insight into the way body size is represented in visual perception and its functional relevance, and (3) developing sound body stimuli in experimental studies on body perception.
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Acknowledgements

There are many people who I would like to thank - for making this thesis possible, for helping me to develop my core research skills, for providing support during difficult times and importantly, for all the laughter. First and foremost, I would like to thank my coordinating supervisor, Jason, for doing each of the above. You are a wonderful supervisor and researcher, who truly cares about his students. I am eternally grateful for the time, encouragement and knowledge you have provided throughout my candidature and in my development as a researcher. I look forward to continuing to work with you in the future.

I would also like to give my thanks to my other wonderful supervisors - Romina, Nadine, and Sue. Romina, thank you for being such a supportive, optimistic and insightful supervisor. Your useful feedback and your guidance throughout my candidature was incredibly helpful. Nadine, despite your move from Australia earlier on in my candidature, you always kept in contact, provided helpful feedback when needed and were always encouraging of my research interests, and for that I am very thankful. Sue, thank you for providing feedback and perspective in the early stages of my candidature.

My sincerest thanks to Dominique and Kendra for their support in data collection for the first and third studies presented in this thesis. I extend my thanks to all of the excellent research collaborators that I have had the honor of working with - Elizabeth Rieger, David Burr and Andrew Meso. To all past and current members of the SNAP Lab and Clinical and Neuro cohorts, I appreciate our insightful chats, friendship and support along the way. Special thanks to Dielle, Annabelle, Laura, Gemma, Rasangi, and Kris, you have become lifelong friends throughout this journey and I appreciate you all very dearly.
My warmest wishes go out to my family, partner and friends. Mum, Dad, Harry, I will be forever thankful for all that you have provided me with and for the enduring love, care and empathic understanding you have given me throughout this journey. Michael, I am indebted to you for the generous and endless support you gave throughout the duration of my thesis. You are a one of a kind human. Your resilience, compassion and positive energy inspires me every day. Zenab and Putri, thank you for listening to me, encouraging me and for consistently making me ‘cry laugh’. Your friendships have been truly enriching to my life and I appreciate the infinite support you have given me. Tarryn, thank you for being an incredible friend to me over the years. Your kind-hearted and warm nature never goes unnoticed.

I would like to acknowledge that this research was supported by an Australian Government Research Training Program (RTP) Scholarship. Finally, I would like to thank staff of the UWA School of Psychological Science and Graduate Research School for providing workshops and events that assisted in the development of my research skills.
Authorship Declaration: Co-authored Publications

This thesis contains work that has been published and prepared for publication.

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| Student contribution to work: (60%). The candidate contributed to the design of the study, data collection and analysis, and was a primary contributor on the manuscript and in subsequent revisions. |

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Chapter 5

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I, Dr. Jason Bell, certify that the student’s statements regarding their contribution to each of the works listed above are correct.

As all co-authors’ signatures could not be obtained, I hereby authorise inclusion of the co-authored work in the thesis.

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Publications Arising from this Thesis

As this thesis is presented as a series of papers, the following manuscripts have either been, submitted and published in international peer-reviewed journals, or are in preparation for submission:


Preamble

This thesis is comprised of six chapters. The first chapter, the General Introduction chapter, provides an overview of the research context and concludes with an outline of the research aims. Following this are four chapters which will present the research relating to the aims outlined in Chapter 1. Finally, the General Discussion is presented in Chapter 6, where the research findings are outlined and implications discussed.

It should be noted that this thesis is presented as a series of research papers, three of which are published in international peer-reviewed journals, and one of which is in preparation for submission (see: Authorship Declaration section for more detail). Therefore, there are some similarities and overlap between each of the main experimental chapters (Chapters 2, 3, 4 and 5) in the conceptualisations, definitions and descriptions of the research. Furthermore, the published research papers included in this thesis have been re-formatted in order to provide a consistent format throughout this thesis.
CHAPTER ONE:

GENERAL INTRODUCTION
Chapter One: General Introduction

1.1 Foreword

The General Introduction section first introduces the topic of eating disorders and includes relevant diagnostic criteria and prevalence statistics, in order to firmly establish the relevance and importance of the current research. Next, the underlying mechanisms involved in body image disturbance, a common feature of eating disorders, are reviewed. In particular, this discussion involves review of the attitudinal, behavioural and perceptual processes that are theorised to be involved in body image disturbances. A summary of known perceptual biases underlying body size misperception (i.e., adaptation and regression to the mean biases) then follows. Serial dependence, a novel perceptual bias, is then introduced as a new potential mechanism contributing to body size misperceptions and perceptual body image disturbances in an eating disorders context. The importance of understanding how robust these perceptual processes and biases are to variations in the experimental context, as is common in the literature, is then discussed. This chapter then concludes with a brief summary and statement of the research aims.

1.2 Characterisation and Prevalence of Eating Disorders

Eating disorders, including anorexia nervosa, bulimia nervosa and binge-eating disorder, are defined as a collection of conditions encompassing an enduring disturbance in eating patterns and body image, which leads to altered food consumption that has a significant and deleterious impact on physical and/or mental health (Ahrberg, Trojca, Nasrawi, & Vocks, 2011; American Psychiatric Association, 2013; Lewer, Nasrawi, Schroeder & Vocks, 2016). Anorexia nervosa, in particular, is a persistent eating disorder that comprises a triad of symptoms, including significantly low weight or weight loss due to energy intake constraints, marked fear of gaining weight or becoming fat and a disturbance over the way one experiences
Anorexia nervosa has been estimated to encompass one of the highest mortality rates of any eating disorder (Arcelus, Mitchell, Wales, & Nielsen, 2011). Furthermore, anorexia nervosa is highly prevalent in young women (13 to 24 years) (The Butterfly Foundation, 2012) in Western countries (e.g., Australia, Europe, United Kingdom and America), where this disorder is estimated to affect between < 1 to 5.7% of the population (Hoek, 2016; Keski-Rahkonen & Mustelin, 2016; Makino, Tsuboi, & Dennerstein, 2004). Prevalence rates for non-Western countries are generally lower, more varied and differ across culture, highlighting the role that sociocultural factors may play in the development of eating disorders (Hoek, 2016; Kolar, Rodriguez, Chams, & Hoek, 2016; Makino et al., 2004; Qian et al., 2013; Van Hoeken, Burns, & Hoek, 2016).

Bulimia nervosa is another commonly experienced eating disorder that encompasses pervasive and enduring body image disturbances (American Psychiatric Association, 2013). Bulimia nervosa is characterised by frequent episodes of binge eating, defined as eating a larger than usual amount of food than would typically be consumed in a similar time period and under similar conditions, and a feeling of lacking control during the binge eating episodes (American Psychiatric Association, 2013). Another core diagnostic criteria of bulimia nervosa is the engagement of compensatory behaviours (e.g., vomiting, excessive exercise, laxative misuse etc.) to prevent weight gain (American Psychiatric Association, 2013). The binge eating and subsequent compensatory behaviours must occur at least once a week for a period of 3 months before a diagnosis is made (American Psychiatric Association, 2013). Similar to anorexia nervosa, bulimia nervosa is also highly prevalent among young women, particularly
between the ages of 16 to 18 (The Butterfly Foundation, 2012). Furthermore, lifetime prevalence rates of bulimia nervosa in Western countries, such as Australia, are estimated to be up to 2.1% (The Butterfly Foundation, 2012). While a Body Mass Index (BMI) requirement is noted in the diagnostic criteria for anorexia nervosa, this is not a diagnostic marker of bulimia nervosa and individuals who do not meet the full criteria of anorexia nervosa may meet criteria for bulimia nervosa (American Psychiatric Association, 2013). Given the similarities between these two eating disorders, it is not surprising that individuals with a diagnosis of anorexia or bulimia nervosa may move between diagnostic categories. In particular, one study indicated that up to one third of individuals diagnosed with anorexia nervosa transitioned over to bulimia nervosa over a seven year period (Eddy et al., 2008). However, this research was conducted prior to updates to the diagnostic classification system, signalling the importance for updated research in this area. Given the high prevalence of eating disorders among young women, the literature discussed within this thesis almost exclusively encompasses this representative sample.

Risk factors for the development and prognosis of anorexia and bulimia nervosa and eating disorders, more broadly, are wide ranging, but tend to encompass several main factors. These factors include: psychological processes, anomalies in genes and biology, aspects of one’s sociocultural environment (e.g., value of thinness in Western societies) and difficulties in childhood development or temperament (American Psychiatric Association, 2013).

Neuropsychological difficulties have also been shown to be involved in eating disorders, hypothesised as both, risk and perpetuating factors of this disorder (Harrison, Tchanturia, & Treasure, 2011; Kanakam, Raoult, Collier, & Treasure, 2013). Specifically, individuals with eating disorders, particularly anorexia nervosa, tend to display a
neuropsychological profile consistent with cognitive inflexibility, a difficulty in adjusting problem solving skills in the face of new information (Arlt et al., 2016; Tchanturia et al., 2012; Tchanturia et al., 2011) and weak central coherence, a cognitive processing style that is characterised by the processing of local detail-oriented information to the detriment of global holistic integration (Lang, Lopez, Stahl, Tchanturia, & Treasure, 2014). It is thought that deficits in these neurocognitive areas might contribute to the clinical features of eating disorder psychopathology, such as a detail-oriented focus (on one’s specific body parts, for example) or rigidity to rules regarding calorie intake (Griffiths, Murray, & Touyz, 2013; Tchanturia et al., 2012).

A variety of evidence-based psychotherapies are used in the treatment of anorexia nervosa and bulimia nervosa (Linardon & Wade, 2018; Murray, Quintana, Loeb, Griffiths, & Le Grange, 2019; Watson & Bulik, 2013). Despite this, it is well known that anorexia and bulimia nervosa can be extremely difficult to treat and relapse rates are very high (> 30%) (Berends, Boonstra, & Van Elburg, 2018; Keel, Dorer, Franko, Jackson, & Herzog, 2005). Additionally, studies have shown that even following successful patient recovery, eating disorder symptoms are likely to persist, putting these individuals at risk of relapse (Steinhausen, 2002). In particular, body image disturbance, one of the main features of eating disorders, has been shown to be among one of the symptoms that predicts relapse in anorexia and bulimia nervosa (Keel et al., 2005). This has consequently led to an increasing amount of research being conducted on the development, maintenance and treatment of body image disturbances.
1.3 Body Image Disturbance in Eating Disorders

Body image disturbance is a complex psychological construct related to eating disorder psychopathology (Cash & Deagle, 1997; Heinberg, 2001; Zanetti, Santonastaso, Sgaravatti, Degortes, & Favaro, 2013). The complexity of this construct lies in the wide ranging components proposed to be involved in a disturbed body image, in addition to the limited research regarding the exact nature of the relationship between these proposed components (i.e., whether there is a cause and effect relationship or whether it is correlational) (Berardi, 2008; Cash & Deagle, 1997). However, there is general consensus, particularly within cognitive-behavioural models of eating disorders, that body image disturbances involve at least three main components: attitudinal (i.e., cognitive and affective), behavioural and perceptual (Berardi, 2008; Bhatnagar, Wisniewski, Solomon, & Heinberg, 2013; Cash & Deagle, 1997; Lewer et al., 2016; Vocks, Legenhauer, Ruddel, & Troje, 2007). While there is still debate within the literature regarding the exact contribution of each component (Dakanalis et al., 2016; Frank & Treasure, 2016; Mölbert et al., 2018), the three components have each been shown to play a significant role in body image disturbances. Critically, these domains of body image disturbance have been hypothesised to play a role in the maintenance of clinically diagnosed eating disorders (Cash & Deagle, 1997; Jansen, Nederkoorn, & Mulkens, 2005; Rosen, Saltzberg, & Srebnik, 1989; Smeets et al., 2011) and in the proliferation of subclinical eating disorder related symptoms in the wider community (Ramsay, Branen, & Snook, 2013). As such, a discussion of the three components of body image disturbance are provided below, with particular focus directed to perceptual mechanisms and their involvement in body size misperceptions.
1.3.1 Attitudinal Components in Body Image Disturbance: Cognition & Affect

The cognitive and affective factors are conceptualised within the ‘attitudinal’ component of body image disturbance (Bhatnagar et al., 2013; Lewer et al., 2016) and encompass the thought processes, emotions and feelings concerning one’s own body in the context of body weight, shape, size or general bodily appearance (Ahrberg et al., 2011; Cash & Deagle, 1997; Vocks et al., 2007). Within this context, it is posited that individuals with eating disorders experience marked distortions in the thought processes and feelings related to their body (e.g., thinking or feeling that one’s body is unattractive, ‘too big’ etc.), which contributes to a disturbance in the way they experience their bodies (Bhatnagar et al., 2013; Lewer et al., 2016).

Regarding the cognitive component, individuals with eating disorders typically engage in unhelpful thinking, termed ‘cognitive distortions’, regarding their own bodies, such as all-or-nothing thinking, biased comparison to others, minimisation of strengths and magnification of perceived flaws (Cash & Pruzinsky, 2002). Attentional biases (i.e., biases in the spatial allocation of attention) are one example of the observable effects of such cognitive distortions (Jansen et al., 2005; Polivy & Herman, 2002; Tuschen-Caffier et al., 2015). It is proposed that individuals with eating disorders process bodily and food related information in a manner consistent with the cognitive distortions regarding their body, which lead to observable attentional biases (Jansen et al., 2005; Polivy & Herman, 2002; Tuschen-Caffier et al., 2015). For example, individuals with anorexia nervosa and bulimia nervosa have been found to selectively attend to their self-reported dissatisfying and ‘ugly’ body parts more than their satisfying and ‘beautiful’ body parts, and this pattern was in contrast to healthy controls (Tuschen-Caffier et al., 2015). This greater attentional bias toward disliked body parts is
thought to reinforce cognitive distortions and maintain disturbances in body image (Tuschen-Caffier et al., 2015). It is theorised that these cognitive distortions are linked to affective components of body image disturbance, by increasing negative emotions regarding aspects of one’s body shape or weight, for example.

### 1.3.2 Behavioural Components in Body Image Disturbance

Behavioural markers related to body image disturbance are often noted within the context of eating disorders too. In particular, bodily avoidance and body checking are frequently reported (Nikodijevic, Buck, Fuller-Tyszkiewicz, Paoli, & Krug, 2018; Shafran, Fairburn, Robinson, & Lask, 2004). Body related checking behaviours involve intense scrutiny over one’s own bodily appearance and the subsequent repeated checking of one’s body weight, size and/or shape via frequent mirror checking, inspecting bone protrusions, pinching skin, compulsive weighing, comparing one’s body to others and the use of clothing sizes to detect changes in body weight (Fairburn, Shafran, & Cooper, 1999; Nikodijevic et al., 2018; Shafran et al., 2004). In contrast, bodily avoidance behaviours involve evading or covering mirrors, avoiding or refusing to be weighed, wearing oversized clothing to hide body weight, size or shape as well as efforts to avoid situations or events that may result in the evaluation of one’s bodily appearance (Nikodijevic et al., 2018; Shafran et al., 2004). Critically, there is evidence to suggest that engagement in body checking and avoidance behaviours are linked to the cognitive processes described above (Smeets et al., 2011), and are associated with body image dissatisfaction (Walker, White, & Srinivasan, 2018), a product of body image disturbance.

### 1.3.3 Perceptual Components in Body Image Disturbance

Body image disturbance refers to the global characteristic affecting individuals with eating disorders. However, body image distortion, is generally referred to as the perceptual
component within body image disturbance (Boepple, Choquette, & Thompson, 2016). As both terms are used in the literature, the terms ‘body image distortion’ and ‘perceptual body image disturbances’ are used throughout this thesis to denote the perceptual component of body image.

Young women with eating disorders have been shown to experience more body-related misperceptions than healthy controls, which have been linked to body image disturbances, a core diagnostic feature of anorexia nervosa (K. Cornelissen, Bester, Cairns, Tovée, & Cornelissen, 2015; Mohr, Rickmeyer, Hummel, Ernst, & Grabhorn, 2016). In particular, individuals with eating disorders, such as anorexia nervosa and bulimia nervosa, tend to overestimate their body size, compared to healthy populations (Gardner & Brown, 2014). These misperceptions have been shown to occur for visual (Gardner & Brown, 2014) and non-visual or sensory modalities (Gaudio, Brooks, & Riva, 2014; Keizer et al., 2013). For example, with regards to the sensory misperception of body size, there is evidence to suggest that individuals with eating disorders tend to misperceive their size when walking through door-like openings (Keizer et al., 2013). This research highlights the pervasive nature of perceptual body image disturbances and reflects the importance of understanding the perceptual factors involved in the perception of body size in dynamic conditions – the topic of Chapter 5.

Typically, individuals with eating disorders will show misperception of body size across multiple sensory modalities, not just one (Gaudio et al., 2014). It is hypothesised that this modality-general body image distortion occurs as a result of difficulty in integrating internal information with information from multiple sensory modalities (e.g., proprioceptive, tactile and visual) into a global and updated body representation, termed multisensory integration (Gaudio et al., 2014; Riva & Dakanalis, 2018; Riva & Gaudio, 2018). Importantly,
while body size misperceptions usually occur in the perception of one’s own body (Gardner & Brown, 2014; Keizer et al., 2013), evidence from typical observers have shown that misperceptions of body size can also extend to other bodies too (Brooks, Mond, Stevenson, & Stephen, 2016; Hummel, Rudolf, Untch, Grabhorn, & Mohr, 2012), highlighting the importance of understanding the mechanisms that cause body size misperceptions more broadly. While individuals with eating disorders tend to experience more body size misperceptions, typical observers are also known to misperceive body size, discussed in further detail below (K. Cornelissen, Gledhill, Cornelissen, & Tovée, 2016). Therefore, examination of body size misperceptions in the general population is also beneficial in the study of the broader perceptual mechanisms involved in body image distortions and eating disorder psychopathology.

One of the main perceptual factors that have been proposed to cause body size misperception are perceptual biases induced by past visual experience. Within this, two main perceptual biases have been proposed to explain the occurrence of body size misperceptions: regression to the mean bias and adaptation bias. Both of these body size biases and their relation to body image distortions are discussed below. These biases are discussed within the modality of visual perception, since this thesis explores body size misperception within this context. Finally, it should also be noted that the studies discussed below regarding body image distortion and biases encompass the use of a broad range of paradigms and stimuli choices, such as real and computer-generated (CG) body images, a point which is important and will be discussed at a later stage of this introduction. However, prior to such a discussion, adaptation bias is first considered below, followed by a discussion regarding regression to the mean bias.
1.3.4 Adaptation Bias in Body Size Misperception

Adaptation aftereffects are a well-established and commonly reported form of perceptual bias, with roots dating back to Aristotle (Verstraten, 1996) and the first published report of this bias occurring almost two hundred years ago (Addams, 1834). Adaptation aftereffects are known to occur when observers view a stimulus for a prolonged period of time (e.g., typically ≥ 5 seconds), termed the ‘adapting’ stimulus, which causes a subsequently viewed, slightly different, test stimulus to appear even more different than it really is (Brooks et al., 2016; Mohr et al., 2016). This resulting aftereffect produces a perceptual bias where the appearance of the test stimuli is ‘repulsed’ away from that of the adaptor stimuli (Clifford et al., 2007). For example, individuals who view a specific facial identity for an extended presentation time are more likely to perceive subsequently presented unique but similar identities as more dissimilar to the adaptor identity than they physically are (Furl, van Rijsbergen, Treves, & Dolan, 2007; Leopold, O’Toole, Vetter, & Blanz, 2001). Accordingly, adaptation bias is suggested to be functionally beneficial to perception, as it facilitates our sensitivity to change between similar, but unique stimuli in the visual environment, by exaggerating these differences (Kristjansson, 2011). Adaptation aftereffects have been reported for a large variety of stimuli, including low-level stimuli such as line orientation (Gibson & Radner, 1937) and contrast (Greenlee & Heitger, 1988) and for higher-level stimuli such as facial identity (Leopold et al., 2001), expression (Fox & Barton, 2007) and more recently, body size (Brooks et al., 2016; Brooks et al., 2020; Challinor et al., 2017; Glauert, Rhodes, Byrne, Fink, & Grammer, 2009; Hummel et al., 2013).

Within the context of body perception, body size adaptation bias has been observed in both, healthy populations and in individuals who have been diagnosed with an eating disorder.
With regards to adaptation bias within the general population, several studies have found that female observers who adapt to thin female bodies subsequently perceive relatively average bodies to be larger than they physically are and vice versa for large adapting bodies (Hummel et al., 2013; Hummel et al., 2012). Importantly, a recent finding showed that participants of an average weight who adapted to thin body images, later perceived their own bodies to be larger than they really were, and increased body dissatisfaction, a psychological facet closely related to eating disorder psychopathology (Bould et al., 2015). However, the exact nature of the relationship between body dissatisfaction and adaptation bias is still a matter of contention (Stephen, Hunter, et al., 2018; Stephen, Sturman, Stevenson, Mond, & Brooks, 2018).

Critically, body size adaptation bias has been recently explored in young women with eating disorders (Mohr et al., 2016). Mohr and colleagues (2016) investigated body image distortions in healthy controls compared to individuals with eating disorders (anorexia nervosa and bulimia nervosa) using an adaptation paradigm. The authors used manipulated (thinner and heavier) photographs of the participants to induce adaptation bias. Healthy controls showed typical adaptation aftereffects, where very thin adapting bodies caused slightly thin body images to appear normal sized and vice versa for large adapting bodies (Mohr et al., 2016). However, individuals with eating disorders displayed an altered adaptation style, such that they showed typical adaptation to large bodies but showed no significant adaptation bias to thin bodies (Mohr et al., 2016). Additionally, the reduced adaptation effect to thin bodies was significantly correlated with eating disorder symptomatology in the eating disorder group, but
not in the healthy control group (Mohr et al., 2016). This finding suggested that the stronger the eating psychopathology is, the smaller the thin adaptation effect is to subsequent ratings of one’s body (Mohr et al., 2016). The authors indicated that these findings reflected that over a long period of time and prolonged exposure to thin bodies in daily life, individuals with eating disorders had altered their sense of a ‘normal’ body size as thinner than actual, and rendered additional adaptation to thin bodies as ineffective (Mohr et al., 2016). Importantly, this research implicated adaptation as one mechanism involved in exaggerated body image disturbance in eating disorder populations (Mohr et al., 2016). This research also validates the importance of investigating perceptual biases in body size, as they can provide information regarding the underlying causes of exaggerated body size misperceptions and body image disturbances, present in eating disorder psychopathology (Mohr et al., 2016).

### 1.3.5 Regression to the Mean in Body Size Misperception

A second form of perceptual bias that contributes towards body size misperception is regression to the mean. Regression to the mean bias is an established bias in magnitude estimation, where estimations of magnitude regress towards the average or mean of a set (Hollingworth, 1910). The term ‘regression to the mean’ denotes the specific phenomenon where magnitude estimations regress to the mean, as opposed to the median or other summary statistics as is typically captured by the overarching term ‘contraction bias’ (Jou, Leka, Rogers, & Matus, 2004). Therefore, the term ‘regression to the mean’ is used throughout this thesis to specifically refer to judgments which regress towards the mean.

Importantly, regression to the mean bias was recently observed in the estimation of body size (K. Cornelissen et al., 2015; K. Cornelissen et al., 2016; Kuchler & Variyam, 2003). Within this literature, it was found that healthy individuals with low body mass indexes (BMIs)
tend to estimate their body to be larger than it physically is, while individuals with high BMIs judge their body to be thinner than reality (K. Cornelissen et al., 2015), consistent with a regression towards the mean size judgment of all previously seen bodies. Conversely, individuals of average BMI have been found to be the most accurate judge of their body size (K. Cornelissen et al., 2015). The finding of a regression to the mean bias has also been extended to the judgment of others’ bodies too (K. Cornelissen et al., 2016). In particular, it has been found that individuals over- and under-estimate thin and large bodies, respectively, in line with a regression toward the mean size of the body set (K. Cornelissen et al., 2016).

Regression to the mean bias is a common observation in healthy participants, and there has been suggestion that individuals with eating disorders exhibit a similar pattern of bias (e.g., P. L. Cornelissen, Johns, & Tovée, 2013). However, other studies have found a different pattern of body size misperception by those with eating disorders (e.g., K. Cornelissen et al., 2015; K. Cornelissen, McCarty, Cornelissen, & Tovée, 2017). Specifically, K. Cornelissen et al. (2015) found that females with anorexia nervosa spectrum disorders did not exhibit regression to the mean bias. Instead, their results showed that body size judgments were largely dependent on these participants’ own weight – those with low BMIs were the most accurate estimators of body size and those with larger BMIs tended to overestimate their size. Furthermore, their findings suggested that psychological symptoms (i.e., depressive states and maladaptive eating disorder related symptoms) had some effect on body size estimations across both, individuals with anorexia nervosa spectrum disorder and healthy controls, changing the overall magnitude of judgments (i.e., the intercept), but not their gradient of responses (i.e., regression to the mean) (K. Cornelissen et al., 2015). That is, both groups who were higher in
psychological symptoms overestimated body size more, than those who reported less psychological symptoms.

Taken together, studies on regression to the mean in body size estimation demonstrate that regression to the mean bias is another source of body size misperception in the general population. However, given regression to the mean is not uniformly seen in those with eating disorders (K. Cornelissen et al., 2015), it seems likely that this bias does not help to explain the additional biases seen in those with eating disorders. Therefore, examining other potential perceptual mechanisms that may underlie and explain the pattern of overestimations seen in those with anorexia nervosa, for example, is particularly important.

1.4 Serial Dependence in Perception

Serial dependence is a newly observed perceptual bias within the vision science literature. Serial dependence was first reported by Corbett, Fischer, and Whitney (2011) for numerosity judgments, and shortly after, extended for line orientation perception (Fischer & Whitney, 2014), where it was found that observers perceived line orientations to be closer to previously seen orientations in the recent past. Importantly, Fischer and Whitney’s (2014) highly influential article regarding serial dependence of orientation perception also incorporated several important control experiments. Through their experiments and through the findings from other research groups, it is now clear that serial dependence induces ‘attractive’ biases, such that perception of a current stimulus is shifted towards perception of recently viewed, similar stimuli in the past.

Importantly, this bias does not occur due to simple averaging across stimuli, since serial dependence occurs almost exclusively for perceptually similar stimuli and not for perceptually distinct stimuli (Fischer & Whitney, 2014). In fact, strongest serial dependencies are usually
found for judgments of ambiguous or less precise stimulus characteristics which are similar in nature, such as similarly oriented Gabor stimuli (Cicchini, Mikellidou, & Burr, 2018). This finding, as well as the statistical models which predict such an effect (e.g., Cicchini et al., 2018), suggest that serial dependence works to increase perceptual efficiency and reduce overall noise, as would be required in conditions where stimuli are perceptually difficult to tell apart (Cicchini, Mikellidou, & Burr, 2017; Cicchini et al., 2018). However, as a result of these processes, larger size misperceptions or errors in the perception of ambiguous stimuli or inter-trial differences are generally observed.

Furthermore, serial dependence bias has also been found to be ‘tuned’ to location. That is, serial dependence biases have been shown to be strongest for perception of stimuli in similar locations, suggesting that this bias is largely spatially specific (Cicchini et al., 2018; Corbett et al., 2011; Fischer & Whitney, 2014). In addition to this, serial dependence operates over relatively short time scales. That is, serial dependence appears to occur across moment-to-moment variations in input, typically biasing perceptual information across a handful of seconds (Fischer & Whitney, 2014), although some preliminary findings posit that serial dependence may also exist in longer (tens of minutes) timescale durations (Gekas, McDermott, & Mamassian, 2019).

1.4.1 Serial Dependence in High Level Stimulus Attributes

Since the initial demonstrations of serial dependence in number (Corbett et al., 2011) and orientation (Fischer & Whitney, 2014), serial dependence has been observed for numerous other perceptual stimuli including for mapping number to space (Cicchini, Anobile, & Burr, 2014), ensemble representations of Gabor patterns (Manassi, Liberman, Chaney, & Whitney, 2017), object position (Manassi, Liberman, Kosovicheva, Zhang, & Whitney, 2018), as well as
for higher-level stimulus attributes, such as for facial identity (Liberman, Fischer, & Whitney, 2014), attractiveness (Taubert, Van der Burg, & Alais, 2016), gender (Taubert, Alais, et al., 2016) and the stability of emotional expression (Liberman, Manassi, & Whitney, 2018; Mei, Chen, & Dong, 2019).

In particular, Liberman et al. (2014) were the first to demonstrate serial dependence bias in higher-level stimuli – facial identity. Their findings revealed that perception of facial identity was significantly ‘attracted’ to identities shown in the preceding trial, in line with a clear serial dependence bias (Liberman et al., 2014). Furthermore, the authors showed that this serial effect remained even when they presented faces at different viewpoints. Taken together, their findings demonstrated that serial dependence is a mechanism that functions across low- and high-level features (Liberman et al., 2014).

Whether serial dependence is one of the causes of body size misperception has yet to be explored. However, given serial dependence operates across other perceptual processes and for other complex stimulus attributes which are closely related to bodies (i.e., faces), it seems reasonable to predict that serial dependence will also operate across body size perception. Therefore, the purpose of the first two studies presented in this thesis was to examine whether serial dependence biases are an underlying source of body size misperception and if so, whether this bias is clinically and functionally relevant to eating disorder symptomatology.

1.5 The Influence of Experimental Factors in Body Size Estimation and Bias

Following the examination of serial dependence bias in body size misperception, the second major aim and section of this thesis is to examine how robust body size estimations are to changes in the experimental environment. For instance, modern research in body size perception is increasingly moving towards the use of computer-generated (CG) body stimuli
(Moussally, Rochat, Posada, & Van der Linden, 2017) as well as the study of body size estimation in dynamic environments, such as those involving active scenes containing moving observers and/or moving stimuli. (e.g., Keizer et al., 2013; Vocks et al., 2007). However, the impact of these changes on body size judgments have not been directly explored. Accordingly, the third and fourth studies of this thesis explore how experimental factors influence body size judgments and whether these situational factors additionally act on related perceptual body size biases. The rationale for the third and fourth studies are considered in greater detail below.

Technological advancements in computer graphics and innovations in experimental methodologies over the last several decades have led to exciting developments in body perception research. Body perception related studies are now increasingly using a diverse range of body stimuli in their investigations, particularly CG body stimuli (K. Cornelissen et al., 2016; Moussally et al., 2017; Vocks et al., 2007). CG body stimuli are particularly advantageous from a methodological standpoint, as they address many of the shortcomings that real body images impose through unwanted heterogeneity of stimuli characteristics (e.g., clothing, pose etc.) and inefficiencies in sourcing real body images (Moussally et al., 2017). CG body stimuli produced through CG imagery software are relatively easy to develop, offer parametric control over attributes and allow for the systematic manipulation of body characteristics, such as size and weight (K. Cornelissen et al., 2016; Moussally et al., 2017). However, representing key body weight markers (e.g., cellulite or emaciation) using synthetic textures can be challenging. Given prior research has identified texture as an important factor in increasing visual realism and suggested that CG faces to do not well represent real equivalents (Crookes et al., 2015), it is plausible that CG body stimuli may less accurately
represent real body size characteristics and consequently impact visual processing, as has been previously shown for face stimuli (Balas & Pacella, 2015; Crookes et al., 2015).

In addition to expanded use of CG body imagery, studies have also begun to examine body size estimation in dynamic environments (Gaudio et al., 2014; Keizer et al., 2013; Vocks et al., 2007). In doing so, this has led to the important discovery that body image distortions occur across multiple sensory domains and are more pervasive in eating disorder populations. For example, a previous study conducted by Keizer et al. (2013) compared healthy controls and individuals with anorexia nervosa on a dynamic aperture task, which involved participants walking through door-like openings that differed in width. Their findings revealed that those with anorexia nervosa significantly overestimated their body size compared to healthy controls, when approaching the apertures. Accordingly, incorporating dynamic environments into research paradigms provides researchers with a platform and means to study body image distortions in other relevant sensory domains other than visual perception. However, there is little, if any, direct consideration of how this dynamic environment might alter overall size estimates or influence specific perceptual biases, such as those outlined above. If we consider the broader literature on perception of dynamic stimuli then there is reason to believe that estimates may be compromised by the dynamic addition. For instance, a previous study by Whitaker, McGraw, and Pearson (1999) found that observers tend to perceive dynamically contracting Gabor patterns as smaller than in conditions where the Gabor stimuli remained static, even though both are the same physical size.

Despite the increased use of CG body stimuli and the dynamic contexts in which body size judgments are being explored, relatively little is known about whether body size estimates and associated perceptual biases of body size are robust to these variations in visual cues or
whether we are biased by these changes. Currently, there is limited evidence in the body size perception literature to answer this question, despite its clear relevance for better understanding the mechanisms underlying body size estimations and related perceptual biases contributing to body image distortions. Therefore, the third and fourth studies presented in this thesis examine whether the use of CG and dynamic body stimuli alters estimates of body size and additionally contributes to body size misperceptions.

1.6 Summary and Research Questions

As outlined earlier in this introductory section, body image disturbances are a core feature of many eating disorders and it is well known that individuals with eating disorders experience greater perceptual distortions of body size. However, the mechanisms underlying these perceptual distortions are less clear, prompting necessary research in elucidating these processes in body size estimation. Recently, a new perceptual mechanism was discovered, termed serial dependence. Serial dependence was originally found in low-level stimulus characteristics such as numerosity (Cicchini et al., 2014; Corbett et al., 2011) and orientation (Fischer & Whitney, 2014), and later discovered for high-level features, such as faces (Liberman et al., 2014). However, it is not yet known whether serial dependence occurs in the perception of bodies. Assuming evidence of this bias is found within body size estimation, it is important to consider the clinical relevance of this form of bias. In addition, it seems sensible to consider whether experimental configurations have a bearing on size estimation accuracy. To do so, two technological transformations of the traditional paradigm were chosen. That is, the move towards synthetic stimuli and also, the shift towards dynamic stimuli that move within the experimental environment. Therefore, the overall aim of the thesis was to contribute
to our understanding of the perceptual factors that underlie body size misperception in healthy individuals, as well as those with, or at risk of developing, an eating disorder.

The specific aims of the studies presented within this thesis are as follows (outlined sequentially in the order of the chapters shown):

i. To test for serial dependence in body size estimation, using a novel paradigm for measuring perceived body size, called the bodyline (Chapter 2).

ii. To examine the clinical relevance of serial dependence by investigating whether serial dependence in body size estimation is associated with eating disorder symptoms (Chapter 3).

iii. To assess the effectiveness of using computer generated body stimuli in the examination of body size estimation and associated biases, regression to the mean and serial dependence (Chapter 4).

iv. To investigate whether body size estimation and associated perceptual biases are robust or sensitive to dynamic conditions, such as when the to-be-judged body appears to move away from the observer (Chapter 5).
Chapter One: General Introduction

1.7 References


doi:10.1002/eat.20336

doi:10.1002/eat.22867


doi:10.1016/S0042-6989(99)00010-3

CHAPTER TWO: PAST VISUAL EXPERIENCES WEIGH IN ON BODY SIZE ESTIMATION

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

Body size is a salient marker of physical health, with extremes implicated in various mental and physical health issues. It is therefore important to understand the mechanisms of perception of body size of self and others. We report a novel technique we term the *bodyline*, based on the numberline technique in numerosity studies. One hundred and three young women judged the size of sequentially presented female body images by positioning a marker on a line, delineated with images of extreme sizes. Participants performed this task easily and well, with average standard deviations less than 6% of the total scale. Critically, judgments of size were biased towards the previously viewed body, demonstrating that serial dependencies occur in the judgment of body size. The magnitude of serial dependence was well predicted by a simple Kalman-filter ideal-observer model, suggesting that serial dependence occurs in an optimal, adaptive way to improve performance in size judgments.
2.2 Introduction

The size of a human body is an important marker of physical health (Wells & Nicholls, 2001). Body Mass Indexes (BMI: mass divided by squared height) of less than 18.5 are clinically underweight (Flegal, Kit, & Graubard, 2014), and can be an important severity marker for anorexia nervosa (American Psychiatric Association, 2013); BMIs greater than 30 are diagnostic of obesity (Flegal, Carroll, Kit, & Ogden, 2012). These extremes are linked to a range of poor health conditions, such as cardiovascular disease, Type 2 diabetes and high blood pressure (Klatzkin, Gaffney, Cyrus, Bigus, & Brownley, 2015), as well as mental health problems, including low self-esteem (Fairburn, Cooper, & Shafran, 2003) and psychopathologies such as impulse control disorders (Borges, Benjet, Medina-Mora, & Miller, 2010; Fernández-Aranda et al., 2006).

Recent research has demonstrated that human observers are often poor at estimating their own body size, and the size of others (Brooks, Mond, Stevenson, & Stephen, 2016; Cornelissen, Gledhill, Cornelissen, & Tovée, 2016; Kuchler & Variyam, 2003). Crucially, body size judgments are not always veridical, but can be biased by various factors. Perceptions can be biased after a prolonged exposure, or adaptation, to a given body type: viewing thin body shapes for a period of time causes subsequently viewed neutral body shapes to appear larger than they do without adaptation, and the opposite occurs after exposure to large bodies (Brooks et al., 2016; Glauert, Rhodes, Byrne, Fink, & Grammer, 2009; Hummel et al., 2013; Hummel, Rudolf, Untch, Grabhorn, & Mohr, 2012; Winkler & Rhodes, 2005). Another type of bias is “central tendency”, or “regression to the mean” a well-known phenomenon in magnitude estimation (Hollingworth, 1910). Cornelissen et al. (2016) have shown that healthy females systematically underestimate the weight of overweight females, and overestimate the
weight of thin females, so errors in magnitude consistently default towards the mean or median of the set, consistent with regression to the mean.

Another form of bias that can occur when judging sequences of images is termed serial dependence. This refers to errors in perceptual judgments consistent with assimilation of the characteristics of the previous stimulus with the current stimulus (the opposite effect of adaptation, described above). Serial dependencies have been observed for a range of visual processes, such as in the perception of orientation (Fischer & Whitney, 2014; John-Saaltink, Kok, Lau, & de Lange, 2016), number (Cicchini, Anobile, & Burr, 2014), face identity (Liberman, Fischer, & Whitney, 2014), attractiveness (Taubert, Van der Burg, & Alais, 2016; Xia, Leib, & Whitney, 2016) and gender (Taubert, Alais, et al., 2016). Although serial dependence results in biasing of perception away from veridical, it has been argued that this is in fact advantageous, increasing efficiency (Burr & Cicchini, 2014; Cicchini et al., 2014), and facilitating the temporal continuity of our perceptual experience (Fischer & Whitney, 2014).

The primary goal of this study was to test for serial dependence in body size estimation. We did this by using a novel technique for measuring perceived body size, which we term the bodyline. It is similar to the numberline technique, now extensively used in studying number perception (Dehaene, 2011), in which subjects position a number along an analogue line, mapping number onto space. Here we ask participants to position a body image along a delineated line, mapping perceived size onto space. The technique is simple, intuitive and reliable. We hypothesized that serial dependencies would occur with judgments of body size.
2.3 Method

2.3.1 Participants

Following standard practices in body size perception research, we restricted our subject sample and stimuli to females. Written informed consent was obtained from all participants. We recruited 103 young female undergraduate psychology students from The University of Western Australia, ranging in age from 17 to 25 years ($M = 18.88, SD = 1.65$). This sample size was chosen in order to obtain a robust measure of serial dependence. BMIs in this group ranged from 16.23 to 43.99 ($M = 22.22, SD = 3.93$). Three additional participants were excluded from the study. Two participants clearly did not attempt to follow instructions to complete the experiment (they had clicked the same area on the bodyline throughout the task). The third participant was excluded because of a computer malfunction. Participants received partial course credit for completing the study. The experimental procedure was approved by the University of Western Australia’s Human Research Ethics Committee and the experiment was performed in accordance with their guidelines and regulations.

2.3.2 Materials and Procedure

The experiment was performed on a host Asus PC running Matlab (The MathWorks Inc, 2013) and the Psychophysics Toolbox (Brainard, 1997). Stimuli were displayed on a ViewPixx monitor with a resolution of 1920 x 1080, showing stimuli at 120 Hz. Each pixel subtended 1’ of visual angle at a set viewing distance of approximately 870mm and the mean luminance of the display was 50.4 cd/m$^2$. Data were analysed using GraphPad Prism software.

2.3.2.1 Stimuli. An initial set of 71 colour images of female bodies (9.6cms x 9.6cms), clothed in either swimwear or underwear, were sourced from the internet and printed onto
cards. They were selected to range from underweight through normal-weight to overweight and obese. Images were cropped in Adobe Photoshop to display the whole body but omit the face, to ensure that facial attractiveness did not bias participants or distract from the judgment of body size. An initial pilot study involved 16 raters (chosen to be broadly comparable to those in the main study) who were asked to group these images into seven distinct categories, ranging from thinnest (category 1) to largest (category 7), along the body size and weight continua. Participants were presented with the stack of body image cards, in no particular order and were instructed to place each of the body images into one of seven categories. Participants were permitted to reconsider their choices during the task. Images were then ranked according to inter-rater agreement and the best category exemplars (those with a clear mode) were chosen for each category, leaving 35 body images in total (five images per category).

In the bodyline experiment, the 35 female body images (approximately 6.5° x 6.5°) were presented on the ViewPixx display for 250 ms each. To reduce visible persistence and colour after images the RGB values in the image were compressed by 80%, towards the middle of the range. Immediately after the stimulus, a large high-contrast visual noise mask (measuring 11° x 11°), comprised of scrambled versions of all the body images, was presented to minimise any visible persistence of the body image.

2.3.3 Procedure

Participants were seated in a quiet room facing a computer screen and keyboard. They were required to judge the perceived size of a briefly presented body stimulus by positioning a marker along the bodyline, a visual analogue scale, consisting of an unmarked line scored linearly as 1.0 – 7.0. The scale was displayed throughout the experiment, together with anchor body images offset one additional unit (1/7th of the scale) from each end of the bodyline,
severely underweight on the left, and severely overweight on the right (see Figure 1). Prior to commencing the study, participants were informed that these anchors were more extreme than any of the body images to be shown in the experiment. On each trial a body was presented for 250 ms, followed immediately by the visual mask for 500 ms. Responses were made by left-clicking the mouse button along the bodyline.

Participants completed 14 practice trials, followed by 3 blocks of 50 experimental trials. The practice trials encompassed the entire range of images, two samples from each category. Participants were then told that this was the entire range, and reminded that the anchor images were more extreme than the bodies to be judged. Images from each of the seven categories were presented in a fixed order across all subjects. Across the 150 total trials that were presented in the experiment, each body size category was both preceded and followed by each other category, including its own category, three times. The three body size judgments were then averaged to form a single number for each of the preceded/followed by category conditions. Lastly, participants’ height and weight were measured to obtain an estimate of Body Mass Index (BMI).
Figure 1. Visual depiction of the bodyline task, in which a female body image was presented for 250 ms, immediately followed by a visual noise mask for 500 ms. Participants indicated the perceived size of the image by clicking on the bodyline delineated with extreme female bodies as anchors presented a further unit of scale beyond the bounds of the numberline. For illustration purposes the females are represented by synthetic body images created in Poser® (Smith Micro Software, 2015).

2.4 Results

We first verified the efficiency of the method to measure perception of body sizes allocated to different categories. Figure 2A plots the mean size judgment given to each of the seven body categories, on linear axes. The data show that mean body size judgments increase monotonically, and almost linearly with physical body size ($R^2=0.99$ for linear fit). This suggests that the size categories were perceived as equidistant. The slope of the linear regression line fitted to the data is less than one, at 0.68 (95% CI: 0.66-0.70). Note that in our study the physical weight of the bodies is not known, and therefore the amount of regression to the mean in our data cannot be precisely calculated. Despite this, our estimated slope is almost identical to that found by Cornelissen et al. (2016) (0.72). Those authors used a different technique for estimating body size but inferred strong regression to the mean in body size estimation, based on a slope less than one. Following the conventions of Cicchini et al. (2012) we define a regression index as the difference from unit slope, an index ranging from zero to 1 (where 1 = total regression to the mean). For the averaged data, this is $1-0.68 = 0.32$ (individual data discussed below).
Figure 2. Average performance in the bodyline task. A. Mean size judgments given to each of the seven categories of body, which varied from very thin to very overweight. Error bars represent ±1 s.e.m. The solid line represents the best fitting linear regression (slope 0.68, $R^2 = 0.99$). The dotted line represents linear use of the bodyline, without scaling. B. Average precision thresholds, given by standard deviation of bodyline judgments, as a function of body category. Bars show 95% confidence intervals, almost all of which span the mean, suggesting that precision varied little with body size.
Participants reported that they found the bodyline technique intuitive and natural. The individual data suggest that they were very consistent in their judgments. The results of all individual participants were well fit by a linear regression, with $R^2 > 0.95$ for the majority of subjects, and $R^2$ always greater than 0.78 (see Figure 3A). Another indication of the consistency of the results is the precision of line-placement. Figure 2B plots the average standard deviations for the bodyline positioning as a function of body category. These are a measure of subject precision, or reliability, calculated separately for each subject, then averaged. There is very little variation in precision with category, except for the extremes, particularly 7, the only point where the 95% confidence intervals do not embrace the global mean. The standard deviations for individual subjects, averaged over categories, are plotted on the abscissa of Figure 3B. The average standard deviation is 0.35 category units, ±0.02 (95% confidence). The ordinate plots the regression index of the individual subjects. The larger the index, the more participants’ responses have tended towards the mean judgment. Again, there was a good deal of variability (Mean = 0.32, SD = 0.13; 95% CI: 0.29-0.34). However, there was no significant correlation between the regression index and precision, as may be expected on theoretical grounds (see modelling section).
Figure 3. Individual data for the bodyline task. A. Histogram showing the distribution of coefficients of determination ($R^2$) for the linear fit. Most are above 0.95, suggesting that the categories were perceived as equidistant, and mapped accurately, save for a scaling constant. B. Regression indexes of the individual subjects (1 minus the slope of best fitting linear regression to their bodyline data) as a function of precision thresholds, defined as average standard deviations for judgments at each category. There is no significant correlation between the two variables. C. Magnitude of serial dependence of individual subjects (defined as the slope of the regression line for similar previous body sizes, illustrated in Figure 4) as a function
of regression index. Again there is no significant correlation, indicating that the two processes are independent. D. Magnitude of serial dependence as a function of precision thresholds. There is a strong and significant correlation, with higher thresholds leading to greater dependency, as predicted by the Kalman filter model (eqn. 8). The top right data point in D is not an outlier but nevertheless we re-ran the analysis without this individual. The correlation remained highly significant: \( r_{(102)} = 0.56, p < .0001. \)

### 2.4.1 Serial Dependence in Body Size

The main goal of this study was to test for serial dependence in body size estimation, that is, whether body size judgments were influenced by the preceding trial. Figure 4 plots the average bias in judgments (the difference between the response and the physical stimulus: \( R_i - X_i \)) as a function of the difference between the physical sizes of the present and past stimuli \( (X_i - X_{i-1}) \). The results were averaged across all participants and all stimulus sizes of the current trial \( (X_i) \). The data clearly show that body size judgments are systematically biased towards prior experience: bodies were perceived as smaller when preceded by a smaller body (lower left quadrant) and perceived as larger when preceded by a larger body (upper right quadrant).

The assimilative bias increased with the difference in size of past and present images, up to a maximum effect for a difference of two body size units, and then reduced in magnitude for larger size differences. This selectivity indicates a highly sophisticated system that assimilates across small but not large size differences. The average data contain a small negative bias (represented by the horizontal dashed line in Figure 4), which passes through the standard errors of the extreme points. The solid curve which generally followed the pattern of the data in Figure 4 is the prediction of an ideal-observer model detailed in the next section.
(eqn. 8). The curve clearly captures the main features of the data: the initial sharp increase in bias, followed by a reduction as the size difference between past and previous stimuli increases. The fit of the model is good, with $R^2 = 0.56$, particularly good when considering that there are no free parameters in the model.

We next examined whether there was any relationship between the magnitude of serial dependence and regression to the mean. A robust estimate of the magnitude of serial dependence of each subject was obtained by fitting a linear regression to the five points nearest to the current stimulus, from $-2$ to $+2$ units, as illustrated by the dashed line of Figure 4 for the aggregate subject data. Figure 3C plots this estimate for each subject against their regression index. There was no significant correlation between the two indexes, suggesting they are independent processes.

We also looked for a correlation between the magnitude of serial dependence and precision thresholds of individual subjects. Figure 3D shows there was a strong and significant positive relationship between these two variables, with correlation coefficient $r = 0.61 (p<0.0001)$. This relationship is predicted by the Kalman filter model described below. The magnitude of serial dependence bias should depend on their noisiness, with greater dependency over a larger range.
Figure 4. Serial dependencies in body size estimation. Data show the average biases in the perceived size (difference between perceived and physical size), as a function of the difference in size of the body on the preceding trial. Data are averaged over all observers and body categories. Error bars represent ±1 s.e.m. The continuous curve shows the predictions of the parameter-free Kalman filter model (eqn. 8). The horizontal dotted line plots the average bias, which is slightly negative. The -6 and +6 conditions yielded only one set of judgments and therefore could not be averaged. Thus, they were excluded from analysis of serial dependence.

2.4.2 Modelling

2.4.2.1 Central tendency in magnitude estimation. Regression to the mean has recently been formulated in Bayesian terms (Cicchini et al., 2012; Jazayeri & Shadlen, 2010),
in which the mean can be considered a prior, the a priori “best guess” before any measurement is made. The prior is statistically combined with the sensory information, termed the likelihood, to yield the most efficient estimate of the judgment (termed the posterior). They show that although it leads to systematic biases towards the mean, this strategy can reduce the overall error (which is a combination of bias and precision) by increasing the precision. The ideal weight given to the prior ($w_p$) should be proportional to the relative reliabilities (inverse variances) of the prior and the likelihood.

$$w_p = \frac{\sigma_p^{-2}}{\sigma_p^{-2} + \sigma_L^{-2}}$$

Where $w_p$ is the ideal weighting of the prior, and $\sigma_p^{-2}$ and $\sigma_L^{-2}$ are the inverse variances of prior and likelihood respectively. Cicchini et al. (2012) demonstrated that the optimal prior width (to minimize error) should depend on both the variance of the likelihood and the range from which stimuli are drawn:

$$\sigma_p^2 = 2\sigma_X^2 - \sigma_L^2$$

Where $\sigma_p$ is the predicted width (standard deviation) of the prior, $\sigma_X$ the standard deviation of the range of stimuli and $\sigma_L$ the standard deviation of the responses. In the current study, the response range was 1-7 (standard deviation 2.1), and standard deviation of the response (likelihood) was on average 0.35 units:

$$\sigma_p^2 = 2 \times 2.1^2 - 0.35^2 = 8.70$$

Substituting the reliabilities of the prior and likelihoods into equ. 1 shows that the ideal weight given to the prior, for maximum reduction of error, should be 0.014, very low indeed. This weight would change the slope of the responses from 1.0 to 0.977, a regression index of 0.023, far lower than Cornelissen et al. (2016) index of 0.28 or our estimated index of 0.32. We
must therefore conclude that the measured central tendency in this and previous studies does not represent an optimal encoding strategy.

**2.4.2.2 Serial dependencies.** We model serial dependencies using the Kalman filter model of Cicchini et al. (2014) which assumes that the response $R_i$ to the current stimulus $X_i$ is given by a weighted sum of the current and previous stimuli:

$$R_i = w_{i-1}X_{i-1} + (1 - w_{i-1})X_i$$

(4)

Where $w_{i-1}$ is the weight given to the previous stimulus. Multiplying out and rearranging predicts the response bias, the difference between response and physical body size ($R_i - X_i$) is given by:

$$R_i - X_i = w_{i-1}(X_i - X_{i-1})=w_{i-1}d$$

(5)

Where $d$ is the difference in physical size between current and previous stimuli ($X_i - X_{i-1}$). According to the Cicchini et al. (2014) model, the weight for the ideal observer is given by:

$$w_{i-1} = \frac{\sigma_i^2}{\sigma_i^2 + \sigma_{i-1}^2 + d^2}$$

(6)

Put simply, the weight should increase with the uncertainty of judging the current stimulus ($\sigma_i^2$), decrease with the uncertainty of the previous stimulus ($\sigma_{i-1}^2$), and also decrease with the squared distance between the current and previous stimulus. As the average root-variance of subjects’ bodyline judgments did not depend strongly on body category (see Figure 2B), we used the average, i.e. $\sigma_i = \sigma_{i-1} = \sigma$. Eqn. 3 then simplifies to:

$$w_{i-1} = \frac{\sigma_i^2}{2\sigma^2 + d^2}$$

(7)

And the predicted bias becomes:
\[ R_i - X_i = \frac{\sigma^2 d}{2\sigma^2 + d^2} = \frac{d}{2 + (d/\sigma)^2} \]  \hspace{1cm} (8)

The solid curve which generally followed the pattern of the data presented in Figure 4 represent the predictions of this parameter-free model, with a fit of \( R^2 = 0.56 \). Inspection of eqn. 5 shows that the amount of bias should depend on \( \sigma \), the noisiness of subjects’ judgments. The bias should continue to increase with \( d \) where \( d < \sigma \), so the larger \( \sigma \) is, the greater the effects should be, over a larger range. Figure 3D shows that the magnitude of the bias does increase with \( \sigma \), with correlation coefficient \( r = 0.61 \) (\( p<0.0001 \)), providing strong support for Burr and Cicchini’s theory (Burr & Cicchini, 2014).

It has been pointed out that serial dependencies do predict a regression to the mean (Cicchini et al., 2014). This is primarily because categories towards the ends of the scale will tend to be preceded by trials that are closer to the mean than they are, hence draw the response towards the mean. We estimated the expected magnitude of serial dependencies on the average judgments with a simple Monte Carlo simulation, calculating the expected response \( R_i \) by reiterating eqn. 5 for all possible combinations of current and previous stimuli. \( w_{i-1} \) was calculated from eqn. 7, with \( \sigma \) given by the measured average observer standard deviation. The predicted regression index was 0.014, far less than Cornelissen and colleagues’ (2016) estimate of 0.28, or our regression index of 0.32. Indeed, the predicted regression index is not too far from that predicted by the ideal observer (0.023), discussed above. This reinforces the suggestion that the two effects are independent of each other, and that regression to the mean does not correspond to an optimal encoding strategy. Instead, the smaller serial dependence could well reflect an optimal encoding strategy.
2.5 Discussion

We devised a novel technique for measuring the perception of body size, which subjects found easy and intuitive. Bodyline judgments were very precise, with average standard deviations of about 0.06 of the scale (0.35 category-units). For all subjects, responses varied linearly with size category, accurate up to a scaling factor.

Despite the linearity and reliability of the judgments, they were not veridical. The data for all subjects was consistent with regression to the mean. While we cannot confirm its magnitude in our data, our estimate was near identical to that reported previously (Cornelissen et al., 2016). Regression to the mean is a well-known and ubiquitous perceptual phenomenon (Hollingworth, 1910) recently explained in Bayesian terms (Cicchini et al., 2012; Jazayeri & Shadlen, 2010) considering the mean as a prior. Within the Bayesian framework, Cicchini et al. (2012) calculate the ideal amount of regression to the mean, given the stimulus range and the precision of subjects’ judgments (eqn. 2). This predicts far less regression to the mean than others have reported (Cornelissen et al., 2016), leading us to conclude that the central tendency observed in body size estimation does not represent an optimal encoding strategy. Perhaps it is simply a tendency for subjects not to use the entire available scale, despite the fact that the anchors flanking the scale at all times were clearly beyond each end of the bodyline. This idea is also supported by the fact that there was no significant correlation between the regression index and serial dependence.

On the other hand, the magnitude of serial dependence was well predicted by the ideal Kalman filter model of Cicchini et al. (2014). The reliance of the effect on the difference in size between the current and present stimulus was well predicted, as was the overall magnitude, with a fit of $R^2 > 0.5$ for a parameter-free model. Furthermore, the magnitude of
serial dependence depended strongly on the precision of each observer, increasing with decreasing precision (increasing thresholds). All this suggests that serial dependencies operate in a flexible, adaptive way to improve performance in size judgments.

Biases in perceived body size owing to visual adaptation have been widely studied (Brooks et al., 2016; Glauert et al., 2009; Hummel et al., 2012; Mohr, Rickmeyer, Hummel, Ernst, & Grabhorn, 2016; Powell et al., 2010). Within this literature, clear differences in the magnitude of body size aftereffects observed for eating disorder groups compared with healthy controls have been reported. These differences suggest that adaptation processes are disturbed in those suffering from an eating disorder (Mohr et al., 2016), which might contribute to the body size misperceptions seen in those with an eating disorder. Further light may be shed on the nature of these differences by new research showing that body size is coded within two separable dimensions, body fat and muscle mass (Brierley et al., 2016; Brooks et al., 2016). However, it remains to be seen whether, and how strongly, serial dependencies contribute to the body-image distortions, observed in those with eating disorders, such as anorexia nervosa and obesity (Cornelissen et al., 2016; Gardner & Brown, 2014; Mussap, McCabe, & Ricciardelli, 2008; Powell et al., 2010), but previous research suggests that they might. For example, it has been reported that variability in body size judgments is associated with a broad range of eating disorder symptoms, including body-image distortion, binge eating and dietary restraint (Mussap et al., 2008). Body image variability then is of clinical relevance. Our results show that serial dependence is strongly correlated with variability in body size judgments (Figure 3D), thus suggesting a possible perceptual explanation for these effects. The bodyline task provides a simple yet sensitive method of investigating whether the newly discovered serial dependencies in perception contribute to eating disorder symptoms and to specific body-
image distortions observed by those at the extremes of the BMI continuum. The method could also prove useful in determining the circumstances under which adaptation rather than serial dependencies occur, since these are far from clear (Burr & Cicchini, 2014; Fischer & Whitney, 2014).

While the current research contributes important new information about serial dependencies and body size perception, a few considerations should be acknowledged. First, since the precise body weights of the female stimuli in our study are not known, we could not accurately measure the overall magnitude of regression to the mean in body size estimation in our data. Although our data resembles what would be expected from regression to the mean, an accurate estimate would require one to use stimuli for which body weight is known. Note however that in research that met this criterion (Cornelissen et al., 2016), an almost identical estimate of regression to the mean was reported (slope of 0.72 vs. our 0.68). Additionally, while this study did not assess male participants on this task, or use male stimuli, it seems likely that a similar pattern of results would be obtained under those circumstances. Thus far, serial dependencies have been shown to occur across a wide range of visual processing tasks (Burr & Cicchini, 2014; Fischer & Whitney, 2014; Liberman et al., 2014; Taubert, Van der Burg, et al., 2016; Xia et al., 2016), suggesting they commonly occur in visual perception. We note that misperceptions in the male assessment of ‘muscular ideals’ have been observed (Sturman, Stephen, Mond, Stevenson, & Brooks, 2017) but it remains to be seen if serial dependencies contribute to these biases. Finally, the current study recruited undergraduate university students, which may have influenced the generalizability of the findings. It is important to extend the current research to a general community sample, where one can expect greater variability in age and BMI, and we intend to do so.
The current research developed a novel technique for examining biases in perceived body size. Our data are consistent with previous reports of regression to the mean in body size judgments (Cornelissen et al., 2016). Additionally, our method reveals evidence of a serial bias in perceived body size, with size judgments tending towards that of the previously viewed body. These findings add to the growing body of literature describing the range of visual processes for which serial dependencies occur.
2.6 References


Chapter Two: Perceptual Biases in Body Size Estimations


Chapter Two: Perceptual Biases in Body Size Estimations


CHAPTER THREE: EVIDENCE FOR A PERCEPTUAL MECHANISM RELATING BODY SIZE Misperception and Eating Disorder Symptoms

Joanna Alexi, Romina Palermo, Elizabeth Rieger & Jason Bell

3.1 Abstract

There are known and serious health risks associated with extreme body weights, including the development of eating disorders. Body size misperceptions are particularly evident in individuals with eating disorders, compared to healthy controls. The present research investigated whether serial dependence, a recently discovered bias in body size judgment, is associated with eating disorder symptomatology. We additionally examined whether this bias operates on holistic body representations or whether it works by distorting specific visual features. A correlational analysis was used to examine the association between serial dependence and eating disorder symptomatology. We used a within subjects experimental design to investigate the holistic nature of this misperception. Participants were 63 young women, who judged the size of upright and inverted female body images using a visual analogue scale and then completed the Eating Disorder Examination-Questionnaire (EDE-Q) to assess eating disorder symptoms. Our findings provide the first evidence of an association between serial dependence and eating disorder symptoms, with significant and positive correlations between body size misperception owing to serial dependence and EDE-Q scores, when controlling for Body Mass Index. Furthermore, we reveal that serial dependence is consistent with distortion of local visual features. Findings are discussed in relation to the broader theories of central coherence, cognitive inflexibility, and multisensory integration difficulties, and as providing a candidate mechanism for body size misperception in an eating disorder population.
3.2 Introduction

Excess body fat is associated with a higher risk of developing coronary artery disease (Jian & Hongliang, 2012), Type 2 diabetes (Dixon, 2010), and stroke (Katsiki, Ntaios, & Vemmos, 2011). Conversely, impaired bone health (Misra, Golden, & Katzman, 2016), pubertal delay (Athey, 2003), and risk to fertility (Tabler, Utz, Smith, Hanson, & Geist, 2018) are among the adverse consequences of very low body weight, a core feature of anorexia nervosa (American Psychiatric Association, 2013). Despite the significance of weight as a potential marker of health, perception of body size is not always veridical. Research has shown that individuals often misperceive their own and others’ physical body shape and weight (Alexi et al., 2018; Brooks, Mond, Stevenson, & Stephen, 2016; Cornelissen, Gledhill, Cornelissen, & Tovée, 2016). This can make it difficult for individuals to effectively recognise weight gain or loss in themselves and others, which may in turn contribute to delayed action or help seeking to modify weight-related health behaviours.

Behavioural, cognitive, affective and perceptual processes are commonly implicated in body image disturbance (Gaudio, Brooks, & Riva, 2014). Behavioural research highlights the impact of bodily avoidance, among other behaviours, which contribute to body image disturbance (Rosen, Saltzberg, & Srebnik, 1989). Cognitive components (e.g., distorted thought patterns) are hypothesised to play a causal role in these behavioural manifestations (Rosen et al., 1989). Additionally, some research suggest that differences in affective processes (such as attitudinal factors regarding one’s body weight (Mölbert et al., 2018)), contribute to body image disturbance, while others emphasise the influence of perceptual biases. Our research focuses on the visual-perceptual causes of body size misperceptions. However, it is important to note that perceptual impairments in body perception may also be non-visual (e.g.,
tactile and proprioceptive) and complex, encompassing multisensory processes (Gaudio et al., 2014).

With regards to perceptual biases, prolonged exposure to visual stimuli can distort the appearance of subsequently viewed, visually related stimuli. This is known as an adaptation aftereffect and adaptation induced biases in perceived body size have been repeatedly demonstrated (Brooks et al., 2016; Hummel et al., 2013; Hummel, Rudolf, Untch, Grabhorn, & Mohr, 2012; Winkler & Rhodes, 2005). A second form of bias in body size judgment can arise due to regression to the mean, whereby judgments of magnitude are biased towards the mean of a set (Hollingworth, 1910). Cornelissen and colleagues (Cornelissen et al., 2016) have demonstrated regression to the mean in body size estimation.

Recently, a third type of bias known as serial dependence was reported in body size estimation (Alexi et al., 2018). Serial dependence is said to occur when errors in perceptual judgments are consistent with the assimilation of features of a previously viewed stimulus with the current stimulus (Alexi et al., 2018; Fischer & Whitney, 2014). That is, judgments are biased towards prior experience. In the context of body size, serial dependencies cause a body to be perceived as smaller when preceded by a smaller body and larger when preceded by a larger body (Alexi et al., 2018). This assimilation is thought to facilitate the temporal continuity of perception (Fischer & Whitney, 2014). Serial dependence differs from adaptation in that it occurs in rapid moment-to-moment judgments and the direction of perceptual bias, towards the prior stimulus, is the opposite of adaptation. Serial dependence occur for a large number of visual processes, including those subserving judgments of visual number (Cicchini, Anobile, & Burr, 2014; Fornaciai & Park, 2018), line orientation (Fischer & Whitney, 2014),
face gender (Taubert et al., 2016), identity (Liberman, Fischer, & Whitney, 2014) and attractiveness (Xia, Leib, & Whitney, 2016) and also body size (Alexi et al., 2018).

While these perceptual sources of bias have been shown to influence the body size estimations of healthy individuals, individuals with eating and weight disorders have been found to display larger misperceptions (Mohr, Rickmeyer, Hummel, Ernst, & Grabhorn, 2016). Preliminary evidence has shown these individuals to exhibit altered patterns of body adaptation (Mohr et al., 2016). However, the question of whether serial dependence biases are associated with eating and weight disorders has not been explored. A novel bodyline task was recently developed by Alexi and colleagues (Alexi et al., 2018). The bodyline task can be used to measure both regression to the mean and serial dependencies, in body size estimation (Alexi et al., 2018). Using this task, the primary goal of the current study was to investigate whether serial dependence is associated with eating disorder symptoms.

In addition to assessing the relevance of serial dependence to eating disorder symptoms, we investigated whether body size biases due to serial dependence can be trivially explained as distortions of a simple visual cue such as horizontal body width, or alternatively, are distortions of holistic body representations. Here, the term ‘holistic’ infers that the bodies have been integrated and processed as a whole, as opposed to being processed as a series of individual features. Recent research demonstrates that holistic processes contribute to body size adaptation effects (Brooks, Clifford, Stevenson, Mond, & Stephen, 2018) but the contribution of holistic body selective processes in serial dependence is yet to be examined.

Past neurobiological methods have revealed that the fusiform body area (FBA) and the extrastriate body area (EBA) are the two main areas of the brain which are involved in holistically processing human bodies (Downing & Peelen, 2016). However, one behavioural
method that can be used to examine whether biases in body size estimation involve such high-level holistic processes is to test for an inversion effect (i.e., a change in bias magnitude due to inverting a stimulus). Inversion effects have been presented as strong evidence for holistic coding of faces, including facial identity (Young, Hellawell, & Hay, 1987) and expression (Calder, Young, Keane, & Dean, 2000). Pertinent to our study, inversion effects have been observed for body posture judgments, implying a holistic representation of body posture (Reed, Stone, Bozova, & Tanaka, 2003). Finding a difference in body size misperception for an inverted versus upright body would be strong evidence that the bias occurs higher in the visual hierarchy, at the level of holistic processing. Conversely, finding no inversion effect would imply the bias is underpinned by distortion of discrete features processed in early, low-level perceptual areas. This represents the second goal of the current study. If body size misperceptions due to serial dependence involve holistic body selective areas of the brain, then we would expect to find inversion effects for bias magnitude.

To summarise, the current study tested for an association between eating disorder symptomatology and bias in body size estimation due to serial dependence. Given previous findings that individuals with eating disorders experience greater body size misperception, we would expect a positive association between the magnitude of serial dependence bias and eating disorder symptomatology. In addition, we investigated whether an inversion effect occurs for serial dependence in body size judgments. If the magnitude of serial dependence differs for upright and inverted stimuli it would be strong evidence that this bias involves high-level holistic body selective visual processes.
Chapter Three: Serial Dependence and Eating Disorder Symptoms

3.3 Method

3.3.1 Participants

A young adult female sample was chosen as eating disorder prevalence is most common in this demographic (Rohde, Stice, Shaw, Gau, & Ohls, 2017). Sixty-three young women took part in the current research. One participant’s data was removed as they did not follow the instructions of the bodyline task. This left 62 participants aged between 17 and 25 years ($M = 20.55, SD = 1.94$). Participant body mass index (BMI = kg/m$^2$) ranged from 16.95 to 30.32 ($M = 22.16, SD = 3.20$). Eating Disorder Examination Questionnaire (EDE-Q) scores ranged from 0 to 4.44 ($M = 1.68, SD = 1.12$).

Participants received course credit for participating or recruiting volunteers. All participants gave written informed consent. The study was approved by the University of Western Australia’s Human Research Ethics Committee and performed in accordance with their guidelines, rules, and regulations.

3.3.2 Materials

The experiment was completed on an Asus PC running Matlab (The MathWorks Inc, 2013) and the Psychophysics-Toolbox (Brainard, 1997). The experiment was presented on a Viewpixx display, resolution of 1920 x 1080 and an average luminance of 50.4 cd/m$^2$. Viewing distance from the computer display was 870 mm. Data were analysed using SPSS and GraphPad Prism. Stimuli were 35 real female body images ($6.5^\circ \times 6.5^\circ$), representing seven discrete categories that ranged from extremely thin to extremely large. The stimuli used in the current study were drawn directly from previous research (Alexi et al., 2018) and a full description can be found in that article. Each of the body images were presented at 20% of
their full contrast. A visual noise mask (measuring 11° x 11°), comprised of various pixels from each of the female body images was also implemented. The visual noise mask was presented to diminish visual persistence of the image.

3.3.2.1 Eating Disorder Examination – Questionnaire. The EDE-Q 6.0 is a well-validated self-report questionnaire version of the widely-used Eating Disorder Examination, which is an interview-based assessment for eating disorder symptoms (Fairburn & Beglin, 1994). The EDE-Q consists of 28 items in total; 22 of the items examine the attitudinal components of eating disorder symptomatology (Mond, Hay, Rodgers, & Owen, 2006). These 22 items form the subscales of Dietary Restraint (5 items), Eating Concern (5 items), Weight Concern (5 items), and Shape Concern (8 items). These items all focus on the preceding 28 days and participants respond to these items using a 7-point, forced-choice, Likert rating scale (0 = complete absence of feature to 6 = acute presentation of feature) (Mond et al., 2006). The remaining six items measure the frequency of engagement in eating disorder behaviours and were not included in the present study. The Cronbach’s alphas for the EDE-Q in the present sample were .70 (Dietary Restraint), .80 (Eating Concern), .83 (Weight Concern), .89 (Shape Concern), and .94 (Total EDE-Q).

3.3.3 Procedure

Each participant completed the experimental task in a quiet room, and were seated facing a computer screen, keyboard and mouse. All participants completed two experimental conditions of the bodyline task: one of which required participants to judge a set of upright female bodies, and the second of which required participants to judge the same set of body images presented to them in an inverted format (Figure 1).
Participants were instructed to judge the perceived size of the body images by left-clicking the mouse along an unmarked visual analogue scale (scored as 1.0 – 7.0), known as the bodyline (Alexi et al., 2018). On each trial, a female body image was presented for 250 milliseconds and was followed immediately by a visual noise mask for 500 milliseconds.

The starting condition was randomised and counterbalanced. Half of the participants completed the upright experimental condition followed by the inverted experimental condition, and vice versa for the remaining half. In both conditions, participants completed 14 practice trials, where they were presented with the full spectrum of images (categories 1-7) twice. Participants were then also informed that the anchors (displaced from each end of the VAS) were smaller and larger than any of the images they would see during the experiment. Following the practice trials, participants completed 3 blocks of 50 trials. Presentation order was fixed across all participants to ensure that within each block of 50 trials, each body size category both preceded and followed each other category, including its own. Following completion of both upright and inverted conditions, participants completed the EDE-Q. Lastly, participants’ height and weight were measured to calculate BMI.
Figure 1. An example of the bodyline task, whereby images of female bodies were presented for 250 ms, subsequently followed by a visual noise mask for 500 ms. Participants were instructed to indicate the perceived size of the body image by left-clicking along the bodyline which depicted extreme female bodies as anchors at each end, beyond the scale. The anchors were more extreme in size than any of the body images presented throughout the task. The bodyline was continuously displayed throughout the experiment. For illustration purposes this figure was created using synthetic body images created in Poser® (Smith Micro Software, 2015).

3.4 Results

The results below are separated into three main components. We firstly report on the data screening and outlier removal process. Next, we present the data showing serial dependence (Figure 2) for the upright and inverted conditions. In doing so, we also present the data relating to our secondary aim, whether an inversion effect occurs for body size judgments.
in serial dependence. We then examine our primary question, are the magnitudes of this bias associated with eating disorder symptoms, as measured using the EDE-Q?

3.4.1 Data Cleaning

Data were assessed for outliers, using the criterion of skew < |2.00| and kurtosis < |7.00| (Curran, West, & Finch, 1996). Additionally, variables were examined according to the outlier criterion of three standard deviations above and below the mean (Howell, 1998). BMI consisted of two outliers using the latter criterion that were subsequently winsorised (Reifman & Keyton, 2010). All other variables were within normal limits.

3.4.2 Serial Dependence Biases in Body Size Judgments

We report the magnitudes of serial dependence in body size estimation for the upright and inverted conditions separately (see Figure 2). Serial dependence was calculated as per the methodologies outlined by Alexi et al. (2018). To summarise, in Figure 2, biases in size judgment (vertical axis) are plotted as a function of the relative size of the previously viewed body (horizontal axis). Location zero zero (i.e., zero on both axes) acts as the comparison condition since here the previous body was the same size as the current body, and thus no bias was predicted. Data falling along the horizontal dotted line would be consistent with veridical or unbiased perception. Instead, the data from both the upright and inverted conditions were consistent with serial dependence, whereby participants were biased by previously viewed body images. The direction of the bias was towards previously seen bodies. Specifically, the lower left quadrant of Figure 2 reveals that participants were biased to see body images as smaller when preceded by a smaller body and vice versa in the top right quadrant. This bias was strongest when the size change from trial to trial was small to moderate (± 2 or 3), and the bias is all but abolished for larger trial to trial body size differences. The data was well fitted by
a Kalman-Filter model as per previous findings (Alexi et al., 2018), $R^2 = .61$ and $.68$, respectively for upright and inverted. This model allowed us to estimate and compare the bias magnitude in each condition. While there was a trend for a larger magnitude of serial dependence in the inverted condition, this difference was not significant ($F(2, 5824) = 2.00, p = 0.14$). Thus, there was no strong evidence of an inversion effect in serial dependence and consequently, no real indication that serial dependence in body size estimation involve holistic body selective processes.

Figure 2. Serial dependence in body size judgments, plotted for upright and inverted conditions. Data display the average biases in the perceived size (comprised of the difference between perceived and actual size), as a function of the size difference of the body on the
preceding trial. Error bars show ± 1 s.e.m. The curved solid black and red lines represent the prediction of the Kalman-filter model for the upright and inverted conditions. The Kalman-filter model used here has been outlined in a previous study (Alexi et al., 2018). The horizontal black dotted line shows veridical or unbiased perception.

### 3.4.3 Are Serial Dependencies Related to Eating Disorder Symptoms?

Having demonstrated the presence of serial dependence in our data, we now turn to our primary question, is there is an association between eating disorder symptomatology, measured using global EDE-Q scores and the magnitude of body size misperception, due to serial dependence? To estimate individual serial dependence magnitudes we simply took the slope of a linear regression fitted to each participant’s data, in each condition. In order to control for the effects of BMI on eating disorder symptomatology, partial correlations are reported.

Results revealed small to moderately sized significant positive correlations between EDE-Q scores, and the magnitude of serial dependence in the upright \( r (59) = .28, p < .05 \) and inverted \( r (59) = .36, p < .01 \) conditions (See Figure 3). These results, the first evaluation of serial dependencies in perception in any clinically relevant context, reveal that participants with higher eating disorder symptomatology experience greater body size misperceptions relating to serial dependence.
Chapter Three: Serial Dependence and Eating Disorder Symptoms

Figure 3. Scatterplots depicting the correlations between EDE-Q scores and serial dependence. Panels A and B depict the correlation between EDE-Q scores and upright and inverted serial dependence variables, respectively. As can be seen, significant small to moderate correlations were found between EDE-Q scores and serial dependence in both conditions.

3.5 Discussion

There were two main goals of the current research. Our primary aim was to examine the association between eating disorder symptomatology and body size misperceptions due to serial dependence. Our secondary aim was to test whether an inversion effect occurs in serial dependence in body size judgments. We discuss the findings of our research in the order of our analyses.

Our data were consistent with previous reports of serial dependence in body size judgments (Alexi et al., 2018), allowing us to address our research questions. With regards to the involvement of holistic processing in serial dependence, we did not find an inversion effect
for serial dependence bias in body size estimation, suggesting that serial dependencies may be
a low-level form of perceptual bias occurring prior to holistic integration. This conclusion is
supported by recent fMRI findings (John-Saaltink, Kok, Lau, & de Lange, 2016) which
suggested serial dependence occurs within the primary visual cortex. Overall then, we
conclude that the distortion of specific visual features, such as hip width, can explain serial
dependence in body size estimation.

Our main goal, however, was to examine the association between eating disorder
symptomatology and body size misperceptions due to serial dependence. Our data revealed that
eating disorder symptoms were significantly and positively associated with serial dependence.
These results demonstrate that participants with higher levels of eating disorder
symptomatology experienced greater body size misperceptions. These findings extend previous
research showing that perceptual adaptation differs in those with a diagnosed eating disorder
(Mohr et al., 2016), by demonstrating a second perceptual process that contributes to clinically
relevant biases in body size perception. Finally, it is worth noting that our bias correctly
predicts the overestimations of body size seen in those with an eating disorder (Gardner &
Brown, 2014). Since those with anorexia would predominantly see other individuals who have
a heavier body size, a serial dependence bias may cause them to misperceive their own body
size as appearing larger than it physically is, as the literature shows.

One speculative explanation for finding a correlation with a low- rather than a high-
level perceptual bias is that those at risk of developing an eating disorder tend towards
processing bodies in a ‘piecemeal’ manner, in line with the weak central coherence theory of
superior local than global processing (Lang, Lopez, Stahl, Tchanturia, & Treasure, 2014).
There is emerging research supporting this view (Urgesi et al., 2014). Urgesi et al. (2014)
examined individuals with anorexia nervosa and found them to have deficient holistic processing for bodies. They proposed that this was related to their perceptual style, which is known to involve obsessive attention to detail of body parts and body size (Urgesi et al., 2014). Furthermore, a meta-analysis (Lang et al., 2014) which examined weak central coherence in individuals with anorexia nervosa concluded that they displayed a superior processing of local information and inefficient processing of global information, compared to healthy controls. Our reports of a correlation between a perceptual bias driven by discrete visual features and eating disorder symptomatology, accords with that view.

Another way of considering our findings is in relation to a cognitive framework. Serial dependence occurs due to the incorporation of past information into our current percept. Individuals with larger serial dependence biases can be thought of as overusing past information, to the detriment of perceptual accuracy. This is loosely consistent with the framework of cognitive inflexibility (Arlt et al., 2016). Cognitive inflexibility is a well-studied neuropsychological construct that is defined by a deficit in the ability to switch between tasks or concepts and a difficulty in adapting when unexpected changes arise (Arlt et al., 2016). Larger serial dependence magnitude in individuals with higher eating disorder symptomatology may be reflective of a perceptual inflexibility to update body size information and minimise past experience. Previous research has revealed that poor central coherence and cognitive inflexibility are prevalent thinking styles in anorexia nervosa (Arlt et al., 2016; Tchanturia, Davies, & Campbell, 2007). Our findings appear to be consistent with this body of literature and lead us to suggest that the neuropsychological deficit of cognitive inflexibility may also be present in the mechanisms of perception.
Alternatively, our results could be interpreted within the context of multisensory body integration. Multisensory body integration has been defined as a process involving the synthesis of sensory processes (e.g., vision and touch) with internal modalities (e.g., interoception), which are then influenced by conceptual (e.g., meaning ascribed to one’s body), perceptual (e.g., size of one’s body), and episodic (e.g., autobiographical events associated with the experience of one’s body) memories (Riva & Dakanalis, 2018). Multisensory integrative processes lead to the emergence of ‘bodily self-consciousness’ and bodily awareness (Riva & Dakanalis, 2018). Within this view, it has been hypothesised that an impairment in multisensory body integration may lead to deficits in the ability to update bodily information (Riva & Gaudio, 2018) (for a review, see: (Riva & Dakanalis, 2018)). While our study involved only one sensory modality, it seems plausible that our results could reflect multisensory integration difficulties in individuals with elevated eating disorder symptoms. Accordingly, future research would benefit from examining the nature of the relationship between cognitive inflexibility, multisensory integration, and serial dependence biases in body size estimation. In turn, this may help to elucidate which of the two processes, cognitive inflexibility or deficient multisensory integration, better aligns with our reported findings.

It should be noted that our study entailed a community sample. Investigating body size misperception due to serial dependence in those with diagnosed eating disorders is therefore warranted. Another potential shortcoming of our study is that it involved the use of two-dimensional images of female bodies. It is of course pertinent to extend our findings to more ecologically valid stimuli, be they avatar based or involving real world settings.

In summary, the present findings provide the first evidence of a relationship between a perceptual mechanism of body size misperception, serial dependence, and eating disorder
symptomatology. This association appears to reflect both, a detail-oriented perceptual style and difficulty in updating, by those with higher eating disorder symptomatology. As outlined above, our findings may prove useful in helping to understand the causes of body size misperception in eating disorder populations. Finally, our findings lead to testable predictions about a possible relationship between cognitive inflexibility, weak central coherence and serial dependence in individuals at risk of developing an eating disorder.
3.6 References


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CHAPTER FOUR: AN ASSESSMENT OF COMPUTER GENERATED STIMULI FOR USE IN STUDIES OF BODY SIZE ESTIMATION AND BIAS

Joanna Alexi, Kendra Dommisse, Dominique Cleary, Romina Palermo, Nadine Kloth & Jason Bell

4.1 Abstract

Inaccurate body size judgments are associated with body image disturbances, a clinical feature of many eating disorders. Accordingly, body related stimuli have become increasingly important in the study of estimation inaccuracies and body image disturbances. Technological advancements in the last decade have led to an increased use of computer generated (CG) body stimuli in body image research. However, recent face perception research has suggested that CG face stimuli are not recognised as readily and may not fully tap facial processing mechanisms. The current study assessed the effectiveness of using CG stimuli in an established body size estimation task (the ‘bodyline’ task). Specifically, we examined whether employing CG body stimuli alters body size judgments and associated estimation biases. One hundred and six 17- to 25-year-old females completed the CG bodyline task, which involved estimating the size of full-length CG body stimuli along a visual analogue scale. Our results show that perception of body size for CG stimuli was non-linear. Participants struggled to discriminate between extreme bodies sizes and overestimated the size change between near to average bodies. Furthermore, one of our measured size estimation biases was larger for CG stimuli. Our collective findings suggest using caution when employing CG stimuli in experimental research on body perception.
4.2 Introduction

Eating disorders are an increasingly prevalent health concern. It is estimated that 15% of Australian women have experienced an eating disorder during their lifetime, which has necessitated clinical intervention (The Butterfly Foundation, 2012). Eating disorders are generally considered as encompassing a pervasive disturbance of eating and/or eating-related behaviours that lead to a disordered consumption or absorption of food and substantial impairments in mental or physical health (American Psychiatric Association, 2013). One of the core diagnostic features in eating disorders, such as anorexia nervosa, is a disturbance in the way one’s body is experienced (American Psychiatric Association, 2013). Additionally, body image disturbance is a clinical marker of many other subtypes of eating disorders too, such as bulimia nervosa and binge-eating disorder (Lewer, Nasrawi, Schroeder, & Vocks, 2016; Zanetti, Santonastaso, Sgaravatti, Degortes, & Favaro, 2013), and it can be very difficult to treat, even following recovery (Eshkevari, Rieger, Longo, Haggard, & Treasure, 2014). It is not surprising then, that a substantial amount of research has been dedicated to understanding the mechanisms underlying body image disturbance (for a review of some of the identified mechanisms, see: Cash and Deagle (1997); Gaudio, Brooks, and Riva (2014); Riva and Dakanalis (2018)). Regarding the perceptual component of body image disturbance, it has been found that that individuals with anorexia nervosa and bulimia nervosa tend to overestimate their body size more than healthy controls (Gardner & Brown, 2014; Vocks, Legenbauer, Ruddel, & Troje, 2007). Several research groups have sought to identify potentially underlying perceptual biases and distortions, such as adaptation, regression to the mean and serial dependence biases, which may be linked to these body image disturbances (see: Alexi et al., 2018; Alexi, Palermo, Rieger, & Bell, 2019; Cornelissen, Gledhill, Cornelissen, & Tovée, 2019).
2016; Mohr, Rickmeyer, Hummel, Ernst, & Grabhorn, 2016; Sturman, Stephen, Mond, Stevenson, & Brooks, 2017). Within this literature, there have been considerable variations in the types of body stimuli used to study judgments of body size and weight.

Early on, methodologies involved the use of schematic drawings of participants’ estimated size (Slade, 1985), distorting mirror techniques (Traub & Orbach, 1964) and silhouette methods (Bell, Kirkpatrick, & Rinn, 1986; Skrzypek, Wehmeier, & Remschmidt, 2001). Researchers then began to use image and video distortion techniques that involved adjusting body image widths to produce a body size change (Skrzypek et al., 2001; Slade, 1985; Taylor & Cooper, 1992). However, it has now been established that horizontal stretching not only gives the body an unrealistic appearance, but can also preserve key size markers in the original image, such as hip-to-waist ratios, which may impact the validity of findings (Dondzilo, Rieger, Jayawardena, & Bell, 2018).

More recently, the advancement and accessibility of photographic and computer graphic technology has led to an increased use of real and computer generated (CG) body images which vary along the continuum, in the study of body image distortion. Real body stimuli have been used in a broad range of body image related studies (e.g., Alexi et al., 2018; Alexi et al., 2019; Blechert, Ansorge, & Tuschen-Caffier, 2010; Hummel et al., 2013), and have the advantage of providing an ecologically representative view of the human body. Real body images are usually acquired by photographing participants or sourced from the internet. However, sourcing real body images using these methodologies can be challenging, particularly if full-length body images varying in body size and weight are required and can result in unwanted heterogeneity due to factors such as clothing, posture and attractiveness, to name a few (Moussally, Rochat, Posada, & Van der Linden, 2017).
CG body image stimuli provide an appealing alternative to real body stimuli, as they address many of these challenges. CG body stimuli are easily created through powerful yet relatively inexpensive CG imagery software that allows for the systematic manipulation of body characteristics, such as weight and size, thus creating precise and reproducible stimulus changes (Moussally et al., 2017). While CG stimuli can be highly human-like in appearance, distinct differences to real photographs are often noted (Fan et al., 2014; Farid & Bravo, 2012). For instance, within the field of face perception and computer graphics, research has identified unrealistic texture, illumination and shading as factors that can decrease realism in CG stimuli (Crookes et al., 2015; Fan, Ng, Herberg, Koenig, & Xin, 2012; Fan et al., 2014).

One concern then, is that the reduction of visual realism in CG stimuli may consequently hamper processing mechanisms. In particular, a face perception study conducted by Crookes et al. (2015) examined how well CG face images tap face expertise abilities by comparing facial recognition abilities for own- and other-race faces across real and CG face images. Their findings revealed that recognition and discrimination accuracy of own-race faces was significantly diminished for CG faces, compared to real faces. The authors concluded that CG face stimuli may not entirely capture and tap face expertise (Crookes et al., 2015). This is likely to be because textural information is important in face recognition (Crookes et al., 2015). These findings are in concordance with other face perception studies, which have found that CG face images disrupt other facial processing mechanisms, such as perception of trustworthiness (Balas & Pacella, 2017) and face memory (Balas & Pacella, 2015).

Conversely, within the body perception literature, there have only been two published comparisons between CG and real bodies that we are aware of. The first by Tovée, Edmonds, and Vuong (2012) and the second by Cornelissen et al. (2016). They found comparable results
between CG and real body stimuli. However, in the first instance, attractiveness and health ratings were compared (Tovée et al., 2012), which are different dimensions of judgment from body size judgments. In the second instance, Cornelissen et al. (2016) compared the use of CG and real body images in the examination of body size sensitivity. However, this comparison used different Body Mass Index (BMI) size ranges between the CG (eight BMI ranges) and real (four BMI ranges) body stimuli (Cornelissen et al., 2016). For example, the largest BMI used in the real body condition was 26.5, versus 43 in the CG condition. Because the stimuli were not matched across each of the BMI groupings, a direct comparison of the two stimulus types appears problematic. Furthermore, if there are variations in body size judgments between CG and real stimuli, these are likely to be more pronounced in statistical extremes, where weight characteristics (e.g., visible emaciation, cellulite etc.) may be less well represented in CG stimuli. Additionally, the question regarding the effect of CG bodies on body size biases, such as serial dependence, is unexplored. Therefore, the current research sought to examine the efficacy of Poser-produced (Smith Micro Software, 2015) CG body stimuli to study body size judgments and whether using CG stimuli alters the magnitude and nature of two known biases that occur in the judgment of body size: regression to the mean and serial dependence.

Regression to the mean is a commonly reported bias in body size judgments (Cornelissen et al., 2016) and this bias occurs when judgments of stimuli are perceived to be closer to the mean of a set than they really are. In a study by Cornelissen, Bester, Cairns, Tovée, and Cornelissen (2015), healthy controls with high psychological symptoms, including depression and eating and weight concerns, were shown to differ in their overall magnitude of body size estimations (i.e., they consistently overestimated their body size), but their slope of
judgments (a common measure of regression to the mean) was unchanged (Cornelissen et al., 2015).

In contrast, serial dependence is a recently discovered bias in body perception, in which perceptual size judgments of stimuli are biased towards the size of previously viewed stimuli. It has been suggested that serial dependence might be particularly strong when the stimuli are relatively ambiguous with respect to the judgment to be made (Cicchini, Mikellidou, & Burr, 2018). It is proposed that this effect occurs because serial dependence works to increase the efficiency of our visual system and reduce overall noise (Cicchini et al., 2018). Serial dependence bias has been observed in the evaluation of a number of different stimuli, such as number (Fornaciai & Park, 2018), orientation (Fischer & Whitney, 2014; John-Saaltink, Kok, Lau, & de Lange, 2016), facial identity (Liberman, Fischer, & Whitney, 2014), attractiveness (Xia, Leib, & Whitney, 2016) and gender (Taubert et al., 2016), and recently, in body size estimation (Alexi et al., 2018; Alexi et al., 2019).

Importantly, serial dependence bias has recently been shown to be associated with eating disorder symptomatology (Alexi et al., 2019). However, this association was found using real body images. We do not know whether the same pattern of results would be evident with CG bodies. Previous research has highlighted the importance of social comparisons of oneself to other individuals’ bodies in predicting body image disturbances (Ridolfi, Myers, Crowther, & Ciesla, 2011; Stormer & Thompson, 1996). Given the reduced realism of CG body stimuli that is highlighted in the face perception literature, it is possible that the impoverished visual information might impact humans’ abilities to relate to CG stimuli in the same way that has been evidenced in social comparison research. If this were the case, the relationship between serial dependence and eating disorder symptoms would likely be
underestimated. Alternatively, it may be that the distinction between CG and real body images is less imperative in body judgments (e.g., Cornelissen et al., 2015; Cornelissen et al., 2016) than it is in other areas (e.g., Crookes et al., 2015), in which case we would expect to see a retention of the significant relationship previously observed between serial dependence and eating disorder symptoms (Alexi et al., 2019).

In order to examine the efficacy of CG body stimuli in the study of body size judgments and their biases, we utilised an established bodyline task (Alexi et al., 2018) for measuring body size estimation and the two aforementioned biases, but we modified the task by presenting CG body stimuli. While there have been some alternative findings in the literature regarding CG and real comparisons, the majority of research in CG imagery seems to indicate that there are subtle differences in the detection and judgment of CG compared to real images, with textural elements noted to play a role (Balas & Pacella, 2015, 2017; Crookes et al., 2015; Johnson et al., 2011; Tinwell, Grimshaw, Nabi, & Williams, 2011). It seems reasonable to predict that textural information is also important in body perception, particularly so for extreme body sizes. For example, key body weight markers, such as visible bone structures in emaciation, or cellulite in obesity appear difficult to fully represent using synthetic textures. Therefore, we hypothesised that perception of CG body stimuli would be non-linear, with poor discrimination amongst extreme weight categories. Poorer discrimination is also predicted to result in larger body size estimation biases, namely regression to the mean and serial dependence (Alexi et al., 2018). Secondly, although speculative and assuming that our initial hypothesis is satisfied, we formed the intuitive hypothesis that CG body stimuli would reduce self-referencing abilities and result in a diminished relationship between serial dependence and eating disorder symptoms.
4.3 Method

The current study was approved by the Human Research Ethics Committee of the University of Western Australia and completed in accordance with their rules, guidelines and regulations. Participation was entirely voluntary and helped to form a component of participants’ undergraduate course credit. All participants provided written informed consent prior to completing the experiment and were debriefed in full following completion of the experiment. Additionally, this study was completed in parallel to the Alexi et al. (2018) study, which established serial dependencies in body size estimations using the bodyline task with real bodies. Therefore, the same sample of participants from Alexi et al. (2018) completed the tasks in the current study.

4.3.1 Participants

One hundred and six female undergraduate psychology students from The University of Western Australia participated in the study. Two participants’ data were removed due to failure to follow the task instructions. A third participant’s data was removed due to a computer malfunction. Therefore, the analyses outlined below were completed using the remaining participants’ data (N = 103). The age of the participants ranged from 17 to 25 years of age (M = 18.88, SD = 1.65) and participants’ BMI ranged from 16.23 to 43.99 (M = 22.22, SD = 3.93). We restricted our sample to females aged between 17 to 25 due to the high prevalence of eating disorders in this sample (The Butterfly Foundation, 2012).

4.3.2 Stimuli

Each of the CG body images were created on computer-generated (CG) software, Poser version 11 (Smith Micro Software, 2015). Poser software was utilised in the current study for
consistency with previous research that regularly employed this software to develop body stimuli (e.g., Cho & Lee, 2013; Glauert, 2008; Nikkelen, Anschutz, Ha, & Engels, 2012). Poser software contains multiple body weight dials, such as the ‘thin’ or ‘heavy’ dials, which can be reduced or increased incrementally when creating body stimuli. Adjusting these dials alters the body weight and size of a chosen CG figure consistent with the descriptor of the dial. The dials ‘thin’, ‘emaciated’, ‘heavy’ and ‘rubenesque’ were chosen for creating our CG body stimuli as they were the most relevant dials to use and produced body types and sizes most consistent with previously established real body images (Alexi et al., 2018).

4.3.2.1 Pilot study to calibrate size range of CG stimuli to prior real body images.

In our earlier work involving real body images, we presented 7 body size categories (Alexi et al., 2018; Alexi et al., 2019). We decided to design CG stimuli that covered the same overall size range as in our previous work. Accordingly, we used Poser software (Smith Micro Software, 2015) to create two sets of CG body images; the first set of three images represented thin endpoint (category 1) real body images and the second set of three matched the heavy (category 7) real body images used by Alexi et al., (2018, 2019). Each set of three body images varied slightly in weight, yet still remained representative of their respective category. We manipulated the ‘thin’ and ‘emaciated’ dials to create the category 1 representative body images. In contrast, the ‘heavy’ and ‘rubenesque’ dials were adjusted to form the category 7 representative body images. Each of the CG body images were created using the CG model ‘Alyson’. The body images were clothed in underwear in order to match previous body images (Alexi et al., 2018; Alexi et al., 2019) and permit view of key body weight markers (e.g., hollowing skin, cellulite etc.).
Using the abovementioned CG body images, a pilot study with five participants was conducted to establish the best matching CG endpoint body categories 1 and 7, with respect to the real body endpoint categories from Alexi and colleagues (2018) study. Participants were first shown the three exemplar category 1 CG body stimuli and each of the five real category 1 bodies used by Alexi et al., (2018). Participants were then asked to choose which of the three CG body stimuli best matched the real category 1 bodies. Using this same methodology, participants then selected the closest CG match to the real category 7 body images.

### 4.3.2.2 Creation of the CG body continuum.

Using the data from our pilot study, the best matched category 1 and 7 CG body images (and body weight dial values) were determined. This selection was based on an inter-rater agreement of ≥ 60%. Following selection of the best matched category 1 and 7 CG bodies, the rest of the full body continuum was created in Poser (Smith Micro Software, 2015). This was done by varying the dial values, as determined by the pilot study, in equal linear steps along the continuum. As the dials ‘thin’ and ‘heavy’ were considered exact opposites of the body weight continuum, we used the difference value between the ‘thin’ and ‘heavy’ dials to divide the two dials into equal increments along the body continuum. The ‘emaciated’ and ‘rubenesque’ dials were also considered to reside on opposite ends of the body weight continuum. Therefore, we applied the above method to the ‘emaciated’ and ‘rubenesque’ dials. Hence, the final CG body continuum resulted in the use of the ‘thin’ and ‘emaciated’ dials for the ‘thinner’ end of the CG body continuum (categories 1 to 3) and then transitioned into the use of the ‘heavy’ and ‘rubenesque’ dials for the ‘heavier’ end of the CG body continuum (categories 4 to 7). The two sets of dials (‘thin’ and ‘heavy’ and ‘emaciated’ and ‘rubenesque’) increased in equal linear
steps along to their respective ends of the continuum, which resulted in a continuous transition from thin to heavy.

Once each of the seven body category dial values had been determined using the above methodology, we created the rest of the CG body image database. This resulted in the creation of 35 CG body images (five images per category) for use in the bodyline task. These body images ranged from extremely underweight to extremely overweight, along the body continuum. The total number of CG body images and body categories were chosen to match the prior real body image database (Alexi et al., 2018; Alexi et al., 2019).

We ensured that our set of CG body images matched the previously established and validated real body images (see: Alexi et al., 2018) on identity and clothing, where possible. We did this by giving the final CG body images variations in pose and clothing to closely match prior research (Alexi et al., 2018; Alexi et al., 2019). While we varied the skin tones of the CG bodies, we used the same model type (model ‘Alyson’) for each of the CG body stimuli. This allowed each of the CG body images to represent a unique identity, and match, as close as possible, the real body images first used in Alexi et al. (2018). As in that study, the images were cropped on Adobe Photoshop to display the whole body but omit the face. The omission of face stimuli in this experiment was deliberately implemented to ensure that the attractiveness of the stimuli did not bias participants’ judgments of size. See Figure 1 for an example of the final seven CG body image categories.

Six CG body anchors (three of which represented an extremely underweight body anchor and three of which represented an extremely overweight body anchor) were also generated in Poser (Smith Micro Software, 2015) using the ‘thin’ and ‘emaciated’ and ‘heavy’ and ‘rubenesque’ dials, respectively. These body anchors were generated to match the
previously established real body anchors on size (Alexi et al., 2018) and to be used as off-scale body anchors denoting the two ends of the visual analogue scale in the bodyline task. They were created to be more extreme in weight than any of the CG body categories, analogous to the real body image database (Alexi et al., 2018). Using the same methodology as in our pilot study, the same five participants were asked to select which one of the three extremely underweight and extremely overweight CG body anchors best matched the real body anchors. The final CG body anchors were selected based on inter-rater agreement of >60%. The CG body anchors were also matched to the real body anchors on identity, clothing, pose and stance.

Figure 1. Example CG body image categories from one (left) to seven (right), which were used in the CG bodyline task. The depicted body images were created with CG imagery software, Poser Version 11 (Smith Micro Software, 2015).

4.3.3 Eating Disorder Examination – Questionnaire 6.0 (EDE-Q)

The EDE-Q is a self-report eating and weight behaviours questionnaire, which was based on the original interview format questionnaire (Fairburn & Beglin, 1994). The EDE-Q comprises 28 items in total, 22 items of which explore overall attitudinal components of eating
disorder symptomatology (Mond, Hay, Rodgers, Owen, & Beumont, 2004). The 22 items form the subscales of Restraint (5 items), Eating Concern (5 items), Weight Concern (5 items) and Shape Concern (8 items). Restraint and Eating Concern subscales measure abnormal eating behaviours, while Weight and Shape Concern subscales examine negative body image, across the preceding 28-day period (Hilbert, De Zwaan, & Braehler, 2012). Respondents answer across a 7-point, forced choice, Likert rating scale (0 = complete absence of feature to 6 = acute presentation of feature) (Hilbert et al., 2012). The remaining six items measure information relevant for diagnosing an eating disorder, such as self-induced vomiting.

Reliability and validity of the EDE-Q are well established (Mond, Hay, Rodgers, & Owen, 2006; Mond et al., 2004). The Cronbach’s alphas for the EDE-Q in our sample were: .80 (Dietary Restraint), .77 (Eating Concern), .91 (Shape Concern) and .84 (Weight Concern).

### 4.3.4 Procedure

Participants were seated in a quiet room facing a computer screen, keyboard and mouse, which the experiment was completed with. The experiment was conducted on an Asus branded PC running Matlab (The MathWorks Inc, 2013) and the Psychophysics Toolbox (Brainard, 1997). The CG body stimuli were shown on a Viewpixx branded PC monitor with a resolution, size and luminance consistent with the previous ‘bodyline’ study by Alexi and colleagues (2018). The size and contrast of the stimuli were also consistent with Alexi et al. (2018).

Participants were given instructions regarding the experiment and were then asked to read an information sheet and sign the corresponding consent form. All participants gave written informed consent and instructed in detail prior to completing the experimental tasks. Following this, participants completed an established bodyline task, which has been shown to
measure both, regression to the mean and serial dependence biases (Alexi et al., 2018). The bodyline task in this experiment was adapted to consist of the CG body images created for this experiment.

During the bodyline task, participants were required to judge the size of various body stimuli, ranging from underweight through average-weight to overweight, using a continuous visual analogue scale (VAS). Participants recorded their responses by left-clicking the mouse along the VAS at the bottom of the screen. The VAS was an unmarked line scored linearly from 1.0 to 7.0, and was present throughout the bodyline task. A CG anchor body image was presented beyond each end of the bodyline scale, demarcating the two extreme weights: extremely underweight and extremely overweight. These anchors were more extreme than any of the body images shown throughout the experiment.

Participants first completed 14 practice trials, followed by 3 blocks of 50 trials. Body stimuli were presented in a fixed order across all subjects, identical to the order presented by Alexi et al., (2018) and Alexi et al. (2019). Each of the body images were presented for 250 ms, followed by a random-noise mask, comprised of scrambled fragments of the CG body images, for 500ms. The noise mask was implemented to interrupt visual processing of the stimuli and to prompt participants for a response. See Figure 2 for a visual depiction of the bodyline task. Upon completion of the bodyline task, participants completed the EDE-Q. Participants’ own height and weight were then measured in order to obtain an estimate of participants’ Body Mass Index (BMI).
Figure 2. A visual representation of the CG bodyline task. The bodyline task required participants to judge the size of CG body stimuli which were presented for 250 ms, followed by a visual noise mask for 500 ms. Participants recorded their body size estimations by left-clicking their mouse along the bodyline, which showed an extreme body anchor displaced from each end of the scale. The anchor images were more extreme in size than all of the body images presented throughout the bodyline task. The bodyline was continuously presented throughout the task. The body images presented here were shown in the experiment and were created using CG imagery software, Poser (Smith Micro Software, 2015).
4.4 Results

The results section first includes a description of the data cleaning process. Secondly, we outline the bodyline, regression to the mean and serial dependence data to provide an examination of our main hypothesis. We then go on to examine our second hypothesis by reporting the correlational analysis between our two perceptual biases and EDE-Q. The data from our pilot study and main results were analysed using SPSS statistical software and Graphpad Prism software.

4.4.1 Data Cleaning and Outlier Removal Process

Before data analysis, the EDE-Q and BMI variables were screened for normality using the criteria of skew $< |2.00|$ and kurtosis $< |7.00|$ (Curran, West, & Finch, 1996). Using these guidelines, our EDE-Q variable was associated with an appropriate level of normality for the purposes of our analyses. However, our BMI variable was associated with a high level of skew (2.19) and kurtosis (8.87), which appeared to be driven by an outlier. Therefore, we analysed the BMI variable using the outlier criterion method of three standard deviations above and below the mean (Howell, 1998). Using this criterion, one outlier was identified and subsequently winsorised (Ghosh & Vogt, 2012; Reifman & Keyton, 2010). Following revision of the outlier through winsorising processes, skew and kurtosis of the BMI variable were reduced to 1.16 and 1.87, respectively. See Table 1 for revised BMI descriptive statistics.
Table 1

Descriptive statistics associated with participant BMI and EDE-Q subscale and global scores.

<table>
<thead>
<tr>
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<th>BMI</th>
<th>EDE-Q R</th>
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<th>EDE-Q SC</th>
<th>EDE-Q WC</th>
<th>EDE-Q G</th>
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</tr>
<tr>
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<td>5.40</td>
<td>6.00</td>
<td>5.60</td>
<td>5.40</td>
</tr>
</tbody>
</table>

Note: M = mean; SD = standard deviation; EDE-Q R = Eating Disorder Examination Questionnaire Restraint Subscale; EDE-Q EC = Eating Disorder Examination Questionnaire Eating Concern Subscale; EDE-Q SC = Eating Disorder Examination Questionnaire Shape Concern Subscale; EDE-Q WC = Eating Disorder Examination Questionnaire Weight Concern Subscale; EDE-Q G = Eating Disorder Examination Questionnaire Global Score.

4.4.2 CG Body Size Estimation and Regression to the Mean

In order to address our main hypothesis regarding the judgment of CG body stimuli, we first report the mean body size judgments of each category when participants were presented with CG body stimuli (see Figure 3). This data relates to our first perceptual bias, regression to the mean. In the next section we will report on the other perceptual bias, serial dependence.

The pattern of responses in the CG bodyline data appear to be a non-linear sigmoidal shape (see Figure 3). Visually, this is reflected by smaller perceived size changes between categories 1-3 and 5-7, while there is a disproportionately large perceived size change between categories 3-5. This non-linear interpretation is supported numerically and statistically. Numerically, we note that 56% of the scale is being used to represent the size change across
near to average size bodies (categories 3-5) while only 44% of the scale is used to represent the size change across the remaining body categories, despite being double in number and bearing in mind that we specifically constructed uniform, linear increments across categories, in Poser. Statistically, the non-linear trend of the data was confirmed by a comparison of fits analysis. This analysis compared a linear fit, as per Alexi et al. (2018), and a non-linear (Cumulative Gaussian) fit, to the CG bodyline data. The analysis revealed statistical support for a non-linear fit, $F(1, 718) = 112.6, p < .0001$. Finally, we note that the non-linear fit was an excellent fit to the data ($R^2 = .91$). We conclude then that the estimation of body size for CG bodies created by our Poser methods is non-linear.

Next we consider the strength of the regression to the mean bias for CG bodies. Fitting a linear regression slope to the bodyline data can provide an estimate of a regression to the mean bias if the slope observed is less than 1.0 (assumed as veridical perception) (Alexi et al., 2018). Applying a linear fit to the CG body data also produced data consistent with regression to the mean (Slope = .79, 95% CI: 0.63 – 0.96). However, since a linear fit is not appropriate for the CG data, this estimate may be problematic to interpret in relation to other regression to the mean estimates.
Figure 3. Visual depiction of the bodyline task data for CG body images. Data show average body size judgments across the seven body image categories. The dotted diagonal line shows unbiased, veridical judgment of the body categories. Error bars depicting S.E.M are plotted.

4.4.3 CG Body Size Estimation and Serial Dependence

As the second part of our main hypothesis we investigated the presence of serial dependence for CG body stimuli. Serial dependence was calculated in accordance with the procedures outlined by Alexi et al. (2018). Figure 4 plots the average bias in body size judgments (i.e., the difference between responses and physical stimuli) along the vertical axis, as a function of the size difference of the previously viewed body image, along the horizontal
axis. As would be expected, no bias was found for trials where the previously seen body was the same category as the current body (location zero on both, horizontal and vertical axes).

Note, data residing on the dotted horizontal line indicated unbiased or veridical body size perception. As can be seen, the CG body data were consistent with serial dependence. That is, participants’ size estimates were biased towards the previously seen body. Specifically, participants were biased to see bodies as thinner than they actually were when they were preceded by thinner body images (see lower left quadrant of Figure 4) and the reverse was true for the larger body categories (see upper right quadrant of Figure 4). The CG body data was well fit ($R^2 = .86$) by a Kalmann-Filter model, as used by Alexi et al. (2018).

Figure 4. Serial dependence bias in body size estimation using CG body images. The data display the average bias in the perceived size (difference between perceived and physical
size of the body images), as a function of the size of the previously viewed body image. Error bars depict ± 1 S.E.M. The solid black curve demonstrates the prediction of the unconstrained Kalman-filter model described in Alexi et al. (2018). The dotted horizontal line shows zero bias in size judgments.

### 4.4.4 Correlational Findings Between Body Size Biases and EDE-Q

Lastly, we examined our final hypothesis, relating to whether the biases observed in the CG body data were associated with EDE-Q. See Table 1 for the descriptive statistics associated with participant EDE-Q subscale and global scores.

We report the correlational findings in the order that we presented the body size biases above. A partial correlation was first conducted between participants’ regression index (i.e., participants’ magnitude of regression to the mean bias) and their associated global EDE-Q score, controlling for BMI. Participant regression indexes were determined using the same methodology as first described by Alexi et al. (2018). The correlation in this study revealed a non-significant association, $r(100) = -.16$, $p = .120$, suggesting a non-significant relationship between regression to the mean bias and eating disorder symptomatology.

Next, we conducted a partial correlation analysis between participants’ magnitude of serial dependence and global EDE-Q, while controlling for BMI. The results from this partial correlation yielded a non-significant association, $r(100) = -.01$, $p = .903$. In a previous study by Alexi and colleagues’ (2019) who used real body stimuli, a significant association between serial dependence magnitude and global EDE-Q was found ($r (59) = .28$, $p < .05$). The discrepancy in findings between Alexi and colleagues’ (2019) findings and our current research may well be explained by the use of the CG body stimuli. The interpretation of this
result is framed within the context of reduced self-comparisons for CG bodies in the Discussion section below.

4.5 Discussion

The current study investigated body size estimations of CG body stimuli. We firstly hypothesised that the perception of sizes of CG bodies would be non-linear, leading to increased perceptual biases, namely regression to the mean and serial dependence. Secondly, we did not expect to find a significant correlation between serial dependence magnitude and eating disorder symptoms when judging CG body images, due to the hypothesised importance of self-reference when judging bodies.

Our findings provided support for our first hypothesis, by showing non-linear body size estimation when participants judged CG body images. The non-linear pattern of the CG bodyline data makes it problematic to provide a sensible estimate of regression to the mean using the traditional linear slope analysis. We can say however, that as predicted, participants clearly found it difficult to discriminate between the more extreme CG size categories (i.e., categories 1 – 3 and 5 – 7), compared to the same real body categories in our previously published work (Alexi et al., 2018), which showed linear discrimination. This finding accords with previous research showing that discrimination and recognition of faces is also significantly reduced for CG faces (Crookes et al., 2015). Therefore, we take the results of our CG bodyline task to suggest that the use of CG body stimuli reduces discriminability between body categories. We hypothesise that this is due to the impoverished representation of textural elements in CG body stimuli. For instance, the smoothing functions in CG Poser software do not well represent the subtle textural differences in skin, such as cellulite, hollowing skin surfaces or visible bones, which observers may use as markers of body weight.
We should point out that two other studies (i.e., Cornelissen et al., 2016; Tovée et al., 2012) which compared the use of real and CG bodies reached alternative conclusions to the current study, as described in the Introduction. This discrepancy in findings may be a result of the type of judgment asked of participants in Tovée and colleagues’ (2012) study or may reflect a lack of sensitivity to the differences in CG and real bodies by using differing BMI ranges to compare performance, as was done in Cornelissen and colleagues’ (2016) study. Alternatively, as previously suggested, it may be that the specific software we used here resulted in stimuli that do not represent body size changes as precisely as other versions or software used in these other studies.

Analysis of the second perceptual bias, serial dependence, provided strong support for our main hypothesis. We found that the serial dependence bias for CG body images was up to 50% larger than the size of the serial dependence effect demonstrated by Alexi et al., (2018) for real body images. This finding can likely be explained by the conditions which are known to increase serial dependence biases. Specifically, serial dependence works to stabilise perception of ambiguous stimuli/scenes, resulting in largest serial dependencies when there is high stimulus uncertainty (Cicchini et al., 2018). Considering that our data suggest poorer (non-linear) discrimination for CG bodies compared to real bodies, we would expect this to manifest in larger serial dependencies for CG than real bodies (Cicchini et al., 2018). Our finding of a larger serial dependence bias for CG bodies accords with this view and is consistent with previous findings (Cicchini et al., 2018). This result signals the importance of using CG body stimuli with caution, as they are more poorly discriminated between than real bodies and participants show larger errors, in the form of larger serial dependence biases, when judging their size.
We next examined the association between the two measured perceptual biases and eating disorder symptomatology. We found no evidence for an association between regression to the mean and eating disorder symptoms. This finding corroborates previous findings by Cornelissen et al. (2015), who found that psychological symptoms had an effect on the overall magnitude of judgments but not the gradient of judgments (i.e., regression to the mean).

However, critically, our results showed that eating disorder symptoms were also not significantly related to serial dependence bias for CG bodies. This finding is of particular interest, considering recent evidence for a significant association between eating disorder symptomatology and serial dependence bias for real body images (Alexi et al., 2019). One possible explanation for the absence of such a relationship in the perception of CG bodies is that this stimulus class may have reduced participant self-comparison to their own bodies. Social comparison theory suggests that individuals compare themselves to others in order to make judgments about their own characteristics (Bessenoff, 2006; Franzoi et al., 2011). In fact, a study conducted by Stormer and Thompson (1996) found that social comparison to others’ bodies was a fundamental contributor to bodily dissatisfaction. Therefore, it is possible that the use of CG bodies led to a reduction in the comparisons of oneself to the CG body images, which may have consequently diminished the effect of individual differences in serial dependence. Together, the correlational findings observed in serial dependence provides support for our second hypothesis as it shows a diminished relationship between EDE-Q and body size biases for CG bodies.

We offer two likely explanations for our collective findings of poorer discrimination and increased errors in the body size estimation of CG bodies. Firstly, as we and others (Crookes et al., 2015) have proposed, poorer discrimination for CG stimuli may reflect an
objective lack of relevant feature information in this stimulus. Research has shown that despite the element of realism that CG imagery can generate, observers are still able to identify a CG image from a real image, suggesting that CG images may be unable to fully capture the nuances of real life stimuli (Farid & Bravo, 2012; Johnson et al., 2011). This failure to fully replicate real bodies leads to less realistic body categories. This may be particularly true for very underweight and very overweight bodies, where skin texture and detailed feature characteristics are particularly important. However, there is a fine line between CG realism and complete human-likeness (Tinwell et al., 2011). Generating CG stimuli which are hyper-realistic may result in the ‘uncanny valley’ effect - a phenomenon whereby observers describe aversive reactions towards hyper-realistic CG characters, due to subtle oddities in their appearance (Tinwell et al., 2011). Importantly, the ‘uncanny valley’ phenomenon demonstrates how attune observers are to the subtle variations in CG imagery, therefore highlighting the importance of providing information-rich and accurate CG body images.

Secondly, our findings may instead reflect a lack of participant exposure to, and familiarity with, CG bodies (Crookes et al., 2015). It is well known that humans develop an expertise in judging human faces (Crookes et al., 2015). Neuropsychological and imaging findings suggest that it is likely that humans develop a similar expertise for perceiving and judging bodies, which is strengthened and fine-tuned over time and with continued exposure (Downing, Jiang, Shuman, & Kanwisher, 2001; Downing & Peelen, 2016; Gillmeister, Stets, Grigorova, & Rigato, 2019; Ishizu, Amemiya, Yumoto, & Kojima, 2010). Given humans view real, not CG bodies, on a daily basis, it is conceivable that our results may instead reflect a reduced expertise for CG bodies. Therefore, it may be particularly important to discern whether our results reflect reduced familiarity with CG bodies or are the result of a poorer ‘make up’ of
the CG bodies used in our task (e.g., less textural information). Future studies may explore the effect that additional training and exposure to CG bodies has on the accuracy of body size judgments (Balas & Pacella, 2015). Alternatively, it may be worth comparing the accuracy of body size estimates between participants who already have substantial exposure to CG imagery (e.g., individuals who frequently play video games involving CG bodies) to those who do not.

Our results highlight the shortcomings of using CG body stimuli in body size estimation tasks. However, we acknowledge the boundaries of our findings are limited to stimuli created with Poser version 11 software. Additionally, given the fast-paced nature of technological advancements in computer graphics, it is important to keep in mind that these results may differ with the use of other Poser versions or with other CG software and in the future with more advanced technology. In fact, some of these advancements are beginning to take shape already. In particular, recent research has begun to incorporate the use of hybrid based body stimuli (Stephen, Sturman, Stevenson, Mond, & Brooks, 2018). This stimulus type typically involves obtaining photographs of real bodies under controlled conditions (e.g., standardised lighting, clothing and photograph angles) which are then systematically manipulated across body weight biomarkers, to create body images that vary along the body weight continuum. This type of manipulation is proposed to simulate typical body weight changes and therefore achieve more realistic transformations in fat mass than previous methods which simply widened or ‘stretched’ images to achieve the appearance of body weight changes (Stephen et al., 2018). Hybrid body stimuli are advantageous in that they incorporate real body images, which are ecologically sound, while also achieving standardised body weight increments, using morphing software. Additionally, new stimulus methodologies have started to incorporate the use of 3D body scanning equipment to create a mesh of participant’s own
bodies, which are then used to generate personalised CG body avatars (Cornelissen, McCarty, Cornelissen, & Tovée, 2017). Using this type of stimulus class may enhance ecological validity by stimulating the act of looking in a mirror when judging body size (Cornelissen et al., 2017). Three-dimensional CG body stimuli have also recently been created and used within the virtual reality context to examine body image distortions (Ferrer-Garcia et al., 2017; Serino, Polli, & Riva, 2019). While these body images are computer-generated, they provide an increased element of realism in their three-dimensional presentation, which may better highlight certain body weight markers (e.g., stomach and thighs). Future research would benefit from understanding whether these stimuli types are more ecologically valid and efficacious than traditional CG stimuli.

In conclusion, the current study examined the effect of CG body images on body size estimation and their associated estimation biases: regression to the mean and serial dependence. Our results suggested poorer discriminability among the CG bodies and larger body size judgment errors, which were demonstrated by larger serial dependencies. Taken together, our results highlight the importance of using caution when employing CG body stimuli in the study of body size estimation and its biases. Furthermore, our findings suggest that care should be taken when interpreting the findings of studies which do use CG bodies. Our combined findings provide useful information to researchers seeking to develop experimental tasks which require the use of body images.
4.6 References


Stormer, S. M., & Thompson, J. K. (1996). Explanations of body image disturbance: a test of maturational status, negative verbal commentary, social comparison, and sociocultural


CHAPTER FIVE: BODY SIZE ESTIMATION ERRORS INCREASE FOR DYNAMIC PRESENTATIONS

Joanna Alexi, Andrew Meso & Jason Bell
5.1 Abstract

Perceptual body image disturbances are commonly reported in individuals with eating disorders, where this clinical feature is most evident. Recent evidence has shown that body image disturbances, particularly in those with eating disorders, extend across multiple perceptual domains including vision, proprioception and motion. Accordingly, these findings have led to the increased study of body size estimation in dynamic environments, or with dynamic body stimuli. However, there is a lack of research regarding whether body size estimates are robust to these experimental conditions. Therefore, the present research examined whether body size estimates and related perceptual biases are robust, or selective, under dynamic conditions, such as when the to-be-judged body appears to contract away from the observer. Fifty seven young adult females between the ages of 17 and 25 participated in the research, which involved estimating the body size of static and dynamically shrinking female body images, along a visual analogue scale. Our findings indicated that dynamically shrinking body images were judged to be smaller overall than static counterparts, in line with the use of local rather than holistic cues to estimate body size. Additionally, our two measured body size biases, regression to the mean and serial dependence, increased for dynamic body images. This finding is discussed within the context of perceptual uncertainty. Collectively, our results indicate the need for careful consideration of how stimulus and experimental design choices might bias body size estimations. Together, these findings can help to advance the literature on perceptual body image disturbance, by providing researchers with critical insights when developing body image related tasks.
5.2 Introduction

Distorted perceptions of our own and others’ body size have been associated with eating disorder related psychopathology (Alexi, Palermo, Rieger, & Bell, 2019; Liechty, 2010; Mohr, Rickmeyer, Hummel, Ernst, & Grabhorn, 2016). In particular, recent work has found that inaccurate body size estimations are related to maladaptive eating and weight-related behaviours (Alexi, Palermo, et al., 2019; Mohr et al., 2016). While healthy observers have been shown to misperceive their own and others’ body size (Alexi et al., 2018; Alexi, Palermo, et al., 2019; Cornelissen, Gledhill, Cornelissen, & Tovée, 2016; Kuchler & Variyam, 2003), individuals with eating disorders, such as anorexia nervosa, exhibit stronger body size distortions than the typical observer (Cornelissen, Bester, Cairns, Tovée, & Cornelissen, 2015; Mohr et al., 2016; Riva & Dakanalis, 2018). Individuals with anorexia nervosa typically perceive their body as larger than it physically is (Cornelissen, McCarty, Cornelissen, & Tovée, 2017; Gardner & Brown, 2014). Furthermore, these body image distortions are generally more pervasive and occur in, and across integration of, multiple perceptual domains, such as vision, touch and proprioception (Gaudio, Brooks, & Riva, 2014; Keizer et al., 2013; Mohr et al., 2016; Zopf, Contini, Fowler, Mondraty, & Williams, 2016). Accordingly, there has been a growing interest in identifying the mechanisms underlying body size estimation across perceptual modalities.

In order to further explore multisensory body image distortions, researchers are increasingly interested in measuring body size judgments in settings which are inherently dynamic (such as in tactile, proprioceptive and motion settings) (see: Gaudio et al., 2014; Keizer et al., 2013; Vocks, Legenbauer, Ruddel, & Troje, 2007). For example, recent works have involved examining the body size estimates of participants’ walking patterns (an example
of a setting involving stimulus motion; Vocks et al., 2007), or of participants’ appraisals to fit through various apertures as they engage in the environment (an example of a setting involving observer motion and proprioception; Keizer et al., 2013). Despite the increasing measurement (both, directly and indirectly) of body size estimates in these dynamic environments, little direct consideration has been given to whether dynamic viewing conditions compromise perceptual accuracy. One sensible place to begin this investigation is by directly comparing body size estimates under traditional static viewing conditions, with those for dynamic body stimuli. In order to create a single dimension of change, and with a desire to employ an ecologically valid manipulation, we simulated a change in viewing distance to the target body by smoothly decreasing the physical size of the image across a half a second presentation.

To the best of our knowledge, no other studies have directly examined whether body size estimates are robust or selective to dynamic changes. However, previous research in the broader perception literature indicates two possible findings regarding the robustness of body size estimates. The first possibility, as suggested through several studies on object size constancy (Andres, McKyton, Ben-Zion, & Zohary, 2017; Sperandio & Chouinard, 2015), is that body size perception will be invariant to uniform image size or scale changes in the estimation of body size. For reference, the term ‘size constancy’ or ‘size invariance’ refers to a crucial perceptual mechanism that facilitates the stable representation of objects, irrespective of changes in viewing distance or the size of the retinal image (Rennig, Karnath, & Huberle, 2013). While our focus is on size constancy1 within the visual-perceptual domain, perceptual constancy, the broader term for this mechanism, has been observed across a number of

1 Please note that the term ‘size constancy’ or ‘size invariance’ used throughout this article refers to the physical size of an image, whereas discussion regarding ‘body size estimation’ refers to the perceptual size of an individual’s body weight within the image. We provide this distinction here in order to reduce confusion associated with the use of these terms.
dimensions, including colour (Hurlbert, 2007), shape (Bell, Dickinson, & Badcock, 2008), faces (B. E. Brooks, Rosielle, & Cooper, 2002) and even viewpoint of bodies (Sekunova, Black, Parkinson, & Barton, 2013). In the current study, size constancy would be evidenced by there being no significant differences in the size judgments of body stimuli which are static to those which are dynamic.

The alternative finding is that body size perception will not exhibit size constancy, but will instead be systematically biased by our dynamic manipulation. Again, previous literature gives weight to this prediction. For example, Whitaker, McGraw, and Pearson (1999) found that the perceived size of dynamically expanding or contracting concentric visual patterns (Gabor stimuli) is biased in the direction of the motion pattern. This demonstrates that patterns of contracting movement can influence size judgments. In addition, selectivity for image size has also been demonstrated for facial processing (Gardiner, Gregg, Mashru, & Thaman, 2001; McKone, 2009). Together, this research provides evidence that visual representations are not always size constant. Accordingly, it is conceivable that the processes underpinning body size estimation will not be robust to our dynamic change in body stimuli, which is consistent with a simple change in viewing distance. According to this literature, particularly Whitaker et al. (1999), we made the prediction that dynamically shrinking bodies would be perceived as smaller than their static counterparts.

Having established our principle experimental hypotheses above, we add to that by considering how specific perceptual mechanisms that are known to contribute to body size estimation biases, are influenced by dynamic stimulus changes. The bodyline task established by Alexi et al. (2018) and adapted here, with the use of static and dynamic body stimuli, provides an ideal paradigm with which to investigate these questions. The bodyline task asks
participants to estimate the size of body stimuli across the body size spectrum, ranging from extremely thin to extremely large. In doing so, we are able to examine average body size judgments for static and dynamic body stimuli and assess whether estimates are robust to, or biased by, dynamic changes (Prediction 1 & 2). In addition, the bodyline task also provides separate and independent measurements of two known causes of body size estimation biases that occur in moment-to-moment perception, serial dependence bias and regression to the mean bias (see: Alexi et al., 2018), but not the longer term body adaptation bias, which requires a different paradigm.

Serial dependence is known to bias perception of body sizes toward previously viewed body images (Alexi et al., 2018; Alexi, Palermo, et al., 2019). Largest serial dependencies have been shown to arise in the presence of greater perceptual uncertainty (Alexi et al., 2018; Alexi, Dommisse, et al., 2019; Alexi, Palermo, et al., 2019; Cicchini, Mikellidou, & Burr, 2017, 2018). In line with this, we predicted that serial dependence biases would increase in the dynamic (less certain) relative to the static (more certain) condition (Alexi et al., 2018; Cicchini et al., 2018). Regression to the mean bias, on the other hand, occurs when judgments of body size regress toward the average of the broader range of body sizes (Alexi et al., 2018; Cornelissen, Gledhill, et al., 2016). Furthermore, regression to the mean bias has also been shown to increase in conditions of uncertainty (Anobile, Cicchini, & Burr, 2012; Ashourian & Loewenstein, 2011). Consistent with these findings and our rationale above, we similarly predicted that regression to the mean would increase in the dynamic, compared to the static condition. Examining these specific mechanisms will extend our main experimental question, by investigating if and how these biases contribute to body size estimation errors in dynamic conditions. In addition, investigation of these mechanisms will further our theoretical
understanding of the ways in which body size perception can come to be biased. Taken together, we examined two alternative predictions regarding size constancy in body size estimation and additionally, considered the influence of serial dependence and regression to the mean biases on estimates of body size in our two experimental conditions.

5.3 Method

5.3.1 Participants

Fifty-seven young women between the ages of 17 and 25 participated in the present study. This young adult female sample was chosen in order to be consistent with prior work on body size perception (Alexi et al., 2018; Hummel, Rudolf, Untch, Grabhorn, & Mohr, 2012). One participant’s data was excluded from subsequent data analysis due to an erroneous response style, leaving 56 participants in total (Age $M = 20.54$, $SD = 1.39$). Participants were recruited through an undergraduate Psychology unit, where completion of this experiment comprised a small component of their unit credit. Participants also recruited others to complete the experiment. Written informed consent was obtained from all participants prior to beginning the experiment. The experiment was conducted under approval from the Human Research Ethics Committee at The University of Western Australia and the experimental procedures were conducted in accordance with their rules, regulations and guidelines.

5.3.2 Materials

The bodyline experiment, described in the Procedure section below, was conducted on an Asus PC running Matlab (The MathWorks Inc, 2013) and the Psychophysics Toolbox (Brainard, 1997). The experiment was displayed on a ViewPixx monitor which comprised a resolution of 1920 x 1080 and a refresh rate of 120 Hz. The average luminance of the display
was 50.4 cd/m². Participants viewed stimuli from approximately 870 mm. GraphPad Prism and SPSS software were used to analyse the data from the current research.

The stimuli used in this experiment were identical to those used in our previous research (i.e., Alexi et al., 2018), which consisted of 35 real female body images, which were perceptually grouped into 7 categories of female body images (5 female body images per category), ranging from extremely thin (category 1) to extremely large (category 7). See Alexi et al., (2018) for a full description of the stimuli and the validation process. The RGB values in the images were compressed by 80% towards the middle of the colour range, to diminish colour after images and visual persistence. A visual noise mask that covered the size of the body images (11° x 11°) was also implemented for use in between trials in order to diminish visual persistence. The noise mask was comprised of scrambled parts of the body stimuli.

5.3.3 Procedure

Participants entered a quiet well-lit room and were seated on a chair, facing a computer screen, keyboard and mouse. Participants were briefed in full regarding the experimental procedure and were subsequently asked to sign a consent form in order to participate in the experiment. All participants gave written informed consent prior to completing the experiment. In total, the experiment took approximately 45 minutes to complete.

Participants completed an adapted version of the bodyline task, originally developed by Alexi et al. (2018). The bodyline task required participants to make judgments of sequentially presented bodies across the body size continuum. On each of the trials, a female body image was shown for 500 ms, immediately followed by the presentation of a visual noise mask, used to diminish visual persistence, for 500ms. Participants judged the bodies using a delineated
visual analogue scale ranging from 1.0 to 7.0. Two anchoring images were presented displaced from either end of the scale at all times throughout the experiment. Participants were told that these anchors were more extreme than any of the body images they would see throughout the task. Participants left-clicked using their mouse, along the visual analogue scale to indicate their body size estimation for each trial. Fourteen practise trials were completed, where two samples from each of the seven body size categories were shown, before participants completed the experiment proper, which comprised 3 blocks of 50 trials each. The body images from the seven categories were shown in a fixed order in the bodyline task. In each of the 50 trials, our experimental order ensured that each of the seven body size categories was both, preceded by and followed by, each other body size category, including its own, an equal number of times. This experimental order allowed us to measure instances of serial dependence.

Each participant completed two conditions of the bodyline task: the static condition, and the dynamic condition. As the name suggests, the static condition required participants to make body size judgments of sequentially presented static (unmoving) female body images. Conversely, in the dynamic condition, participants made body size judgments of contracting female body images. The body images in the dynamic condition contracted by 50% across the 500 ms presentation. The order of the static and dynamic conditions were counterbalanced and participants completed both conditions. Following completion of their first allocated condition, participants watched a brief distractor video unrelated to body image and answered several short questions before beginning the second condition.
Figure 1. A graphical representation of the endpoints of the dynamic condition in the bodyline task. For each trial within the dynamic condition, a single body image which contracted to half of its original size was presented to participants in a fixed order sequence. The static and dynamic body images were presented for 500 ms, followed by a visual noise mask for 500 ms. The visual noise mask then disappeared, prompting participants to make a body size judgment of the presented body image. The delineated visual analogue scale was
presented throughout the entire experimental task and contained an extremely thin and large anchor displaced on the left and right ends of the scale, respectively. The static condition looked like the starting image of the dynamic sequence but remained constant across the identical 500 ms presentation. This figure was created using computer-generated body images in Poser (Smith Micro Software, 2015) for pictorial purposes.

5.4 Results

Figure 2 shows the mean body size judgments for each of the seven body size categories, by condition. Static condition data are represented by the solid black squares and dynamic condition data by the solid red circles. Plotted this way, the data appear to show a systematic shift in body estimates and a change in regression to the mean bias, as we will go on to explain. Serial dependence requires further transformation of the data and will be considered separately. The primary research question, does dynamic movement of the to-be-judged body influence body size estimation? can be addressed by assessing the main effect of body dynamism in a 2 (static vs dynamic condition) x 7 (body size judgments of categories 1 to 7) repeated measures 2-way ANOVA. Prior to running the ANOVA, the data were assessed to be adequately normal for parametric testing using the normality criterion cut-off of skew < |2.00| and kurtosis < |7.00| (Curran, West, & Finch, 1996). Conversely, the assumption of sphericity was not satisfied according to Mauchly’s test of sphericity, $\chi^2(20) = 52.52, p < .001$ (interaction effect) and $\chi^2(20) = 278.88, p < .001$ (main effect of body size judgments). Therefore, the results of the ANOVA are reported using a Greenhouse-Geisser correction. As expected, the main effect of body size category was significant ($F(2.37, 130.45) = 1395.72, p < .001, \eta^2_{\text{partial}} = .962$), indicating that participants judged the collective body size categories significantly different from each other category. The result of the main effect for body
dynamism was significant ($F(1, 55) = 25.18, p < .001, \eta^2\text{ partial} = .314$) consistent with participants making overall smaller body sizes estimates for dynamically shrinking bodies; i.e. scale selectivity. Indeed, as shown in Table 1, mean dynamic condition estimates were numerically smaller than those of the static condition in six of the seven body size categories and significantly smaller in four out of seven. However, this interpretation needs to be qualified in light of the significant interaction between body size and condition ($F(4.31, 236.77) = 19.35, p < .001, \eta^2\text{ partial} = .260$). At this stage we remind the reader that an increase in regression to mean bias alone in the dynamic condition would predict an interaction, but no main effect of body dynamism. By fitting a linear regression to the data in each condition (Alexi et al., 2018) we were able to confirm that there is an increase in regression to the mean bias in the dynamic condition, i.e. a significantly more shallow slope in the dynamic (.69, 95% CI: .59 to .79) versus static condition (.74, 95% CI: .65 to .83), $F(1, 780) = 9.01, p < .05$. This finding indicates that dynamic movement does increase one measured form of perceptual bias, regression to the mean.

Taken together, we conclude that adding dynamic movement to a viewed female body, consistent with an increase in distance from the observer, influences the perceived size of a female body. This is consistent with the use of a single, or local visual feature that scales (e.g. body width, rather than a ratio measure that is constant, such as hip-to-waist ratio). We propose that the reason this influence was not evenly exhibited across all categories was because the dynamic movement simultaneously increased regression to the mean bias. We will give further justification for that conclusion in the discussion but for now, we turn our attention to the measured serial dependencies in the data, and whether that form of perceptual bias similarly shows an increased magnitude in the dynamic condition.
Figure 2. The bodyline data for the static and dynamic experimental conditions. Data depict average body size judgments given to each of the seven body size categories. The dotted diagonal line represents unbiased linear judgments of the categories. Error bars depicting S.E.M are plotted.
Chapter Five: Body Size Estimation of Dynamic Bodies

Table 1

*Paired samples t tests and associated descriptive statistics between the static and dynamic conditions for each of the body size categories.*

<table>
<thead>
<tr>
<th>Category</th>
<th>Static M (SD)</th>
<th>Dynamic M (SD)</th>
</tr>
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<tbody>
<tr>
<td>Category 1</td>
<td>1.50 (.40)</td>
<td>1.63 (.41)</td>
</tr>
<tr>
<td>Category 2</td>
<td>1.99 (.53)</td>
<td>1.96 (.50)</td>
</tr>
<tr>
<td>Category 3</td>
<td>2.67 (.55)</td>
<td>2.65 (.51)</td>
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<tr>
<td>Category 4</td>
<td>3.59 (.55)</td>
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<tr>
<td>Category 5</td>
<td>4.37 (.50)</td>
<td>4.13 (.52)</td>
</tr>
<tr>
<td>Category 6</td>
<td>4.76 (.46)</td>
<td>4.57 (.42)</td>
</tr>
<tr>
<td>Category 7</td>
<td>5.96 (.34)</td>
<td>5.75 (.33)</td>
</tr>
</tbody>
</table>

Note: *M = mean, SD = standard deviation. Each of the df in the t test analyses above were 55. Significant *p* values are indicated with an asterisk. In order to correct for multiple comparisons, we used a Bonferroni correction. All *p* values below .007 were considered significant according to the correction applied.

We next measured the serial dependence biases in our two experimental conditions. Serial dependence bias was calculated using the same methodologies used originally in Alexi et al. (2018). We then plotted the average bias in body size judgments against the relative size of the previous image (see Figure 3). Location zero on both, the horizontal and vertical axes, indicates that the current and past body size categories were identical. This condition was used as the comparison condition, since no bias is predicted here. Data falling along the dashed horizontal line indicates nonbiased perception. As can be seen in Figure 3, the data for the static and dynamic conditions showed that participant judgments were biased towards...
previously seen bodies, consistent with a serial dependence bias. That is, participants perceived body images to be larger than they physically were if they were preceded by larger bodies (demonstrated in the upper right quadrant) and smaller if they were preceded by smaller bodies (observed in the lower left quadrant). Consistent with prior findings (see: Alexi et al., 2018; Alexi, Dommisse, et al., 2019; Alexi, Palermo, et al., 2019), our results showed a strongest serial bias for small to medium, trial to trial stimulus differences (± 1 to 2 body size categories), where stimulus uncertainty between trials would have been largest, and a subsequent reduction of bias for large inter-trial stimulus differences (± 4 to 5 body size categories), where stimulus uncertainty between trials would have been lowest.

In line with previous literature (Alexi et al., 2018; Alexi, Dommisse, et al., 2019; Alexi, Palermo, et al., 2019), the static and dynamic data were fit by a Kalmann-Filter ideal observer model, $R^2 = .58$ (static) and $R^2 = .64$ (dynamic). We used this model to compare bias magnitude for the static and dynamic conditions. As shown in Figure 3, the dynamic condition (depicted by the red circles and solid red line for the data and model predictions, respectively) shows a greater serial dependence bias magnitude than in the static condition (depicted by the black squares and solid black line for the data and model predictions, respectively). Importantly, this difference in bias magnitude between the static and dynamic conditions was shown to be statistically significantly different, $F(1, 5260) = 4.24, p < .05$. The larger serial dependencies found in the dynamic condition appears consistent with previous research which has observed larger serial biases for stimuli which are considered more ambiguous or uncertain (Alexi et al., 2018; Cicchini et al., 2018). Together, these results demonstrate serial dependence as a second bias that increases in magnitude for dynamically changing bodies. The collective
finding of increased biases in the dynamic condition are further considered in the Discussion section below, in the context of perceptual uncertainty.

Figure 3. Visual depiction of serial dependence bias in body size judgments in the static and dynamic conditions. The data here demonstrates the average bias in perceived body size (the difference between the physical and perceived sizes for each body image condition). Error bars show ± 1 S.E.M. The solid black (static condition) and red (dynamic condition) curves show the prediction of the Kalman-filter model outlined in Alexi et al. (2018). The horizontal dotted line represents unbiased body size judgments. The data show that dynamic body size estimations are more strongly biased by previously viewed body images, in line with a stronger serial dependence bias for dynamic bodies.
5.5 Discussion

The main aim of the current study was to examine whether body size estimates are robust or selective to dynamic body images, in comparison to static equivalents. In doing so, we additionally considered how two known body size estimation biases, regression to the mean and serial dependence, are influenced by dynamic stimulus changes.

Regarding our main experimental aim, our findings indicated that body size estimates were not size constant (i.e., robust) to dynamically shrinking body images. This was evidenced by a significant main effect for body dynamism which indicated overall smaller body size judgments in the dynamic condition, in comparison to the static condition. Numerically, the finding of smaller body size estimates for the dynamic relative to the static body images was observed for all but one body size category, and significant for more than half of the seven comparisons. Considered alone, these results indicate that body size estimates are, at least in part, sensitive for the scale changes of the body images, such as when the to-be-judged body appears to move away from the observer.

Our question of size constancy can also be conceptualized as a broader test of whether body size representations are scale invariant, suggesting use of some holistic metric (e.g., hip-to-waist ratio) as found for body viewpoints (Sekunova et al., 2013) and other perceptual processes, such as adaptation (K. R. Brooks, Clifford, Stevenson, Mond, & Stephen, 2018). Holistic processing refers to the processing of stimuli, particularly for faces and bodies, as a gestalt whole rather than the simple sum of its parts (Hart, 2016; Maurer, Le Grand, & Mondloch, 2002; Reed, Stone, Bozova, & Tanaka, 2003). This mechanism is in contrast to featural processing, which involves the processing of individual parts of a stimulus (Maurer et al., 2002). Therefore, it could be said that the finding of scale selectivity here provides
evidence that observers make use of local visual cues (e.g., thigh width), in the estimation of body size. This result also seems consistent with the finding that typical observers tend to demonstrate fixation patterns, as measured using eye movement tracking technology, on specific bodily features (e.g., abdomen) when estimating body size changes (Cornelissen, Cornelissen, Hancock, & Tovee, 2016).

An important caveat to the interpretation of a simple size or scale selective account of body size is that a significant interaction effect between the static and dynamic conditions was also observed. Although nearly all (6/7) body size estimates were smaller for the dynamic condition, this result was not true for all body size categories. In particular, category 1 was actually perceived to be significantly larger in the dynamic relative to the static condition, contributing to the interaction between the two experimental conditions. A significant interaction would not be predicted if body size estimates were solely influenced by the size or scale of the image. Therefore, in light of the significant interaction, and given our predictions regarding larger biases in the dynamic condition due to increased perceptual uncertainty, we further explored our main experimental question by examining how dynamic changes influence regression to the mean and serial dependence biases in body size estimation.

First, regression to the mean bias is considered. Our results revealed a significantly flatter slope in the dynamic condition, consistent with a stronger regression to the mean bias for dynamic bodies, relative to the static equivalents. Importantly, the greater regression to the mean bias shown for the dynamic condition meant that while most body categories were judged as smaller, increased regression to the mean inflated judgments of the lower than average body size categories in this condition, compared to the static condition, as shown in Figure 2. We next evaluated the second measured body size bias, serial dependence. In line
with our findings of greater regression to the mean in the dynamic condition, serial dependence was also significantly larger in the dynamic relative to the static condition.

We take the finding of increased perceptual biases, in the form of regression to the mean and serial dependence, to reflect the increased uncertainty that is associated with the processing of dynamic body stimuli. This interpretation is consistent with the broader perception literature which has demonstrated larger regression to the mean and serial dependence biases in conditions of high perceptual uncertainty, such as when observers are required to judge relatively ambiguous stimulus orientations from trial-to-trial (e.g., Cicchini et al., 2018) or following distractor tasks (Ashourian & Loewenstein, 2011). Furthermore, this interpretation accords with our recent work that has found greatest serial dependencies between perceptually ambiguous differences in body size categories from trial to trial (Alexi et al., 2018; Alexi, Palermo, et al., 2019) and crucially, as a broader result of ambiguous stimulus characteristics (i.e., computer-generated body images; Alexi, Dommesse, et al., 2019). It is suggested that serial dependence bias increases with perceptual uncertainty as a result of its role in improving the efficiency and perceptual continuity of our visual system (Cicchini et al., 2018; Fischer & Whitney, 2014). If body size estimations were influenced by the scale changes of a body image, but there was no accompanying increase in perceptual uncertainty, then we would not predict increased perceptual biases under dynamic body size estimation conditions. Instead, our data showed significantly greater serial dependence and regression to the mean biases in the dynamic relative to the static condition, highlighting the role of perceptual uncertainty in the estimation of body size. Taken together, our combined findings show evidence of smaller body size estimates in the dynamic condition and greater body size estimation biases, due to regression to the mean and serial dependence. Therefore, our data
indicate that body size processing mechanisms are scale selective and influenced by the perceptual uncertainty of the stimulus.

Collectively, these findings provide critical information for researchers interested in examining body size estimation or perceptual body image distortions in dynamic environments, such as those involving observer motion (Keizer et al., 2013) or with dynamic body stimuli (Vocks et al., 2007). Previously, studies which have examined body size misperceptions in dynamic environments (e.g., Keizer et al., 2013) or with dynamic stimuli (e.g., Vocks et al., 2007), have not directly considered whether these body size distortions are influenced by the dynamic manipulation itself. Our findings indicate that body size estimates are selective to, and biased by, dynamic changes in the physical size of the image, leading to larger errors in body size judgments. Accordingly, we suggest that researchers use caution and consideration in the design of body image experiments that require movement of the observer, or of the to-be-judged body, as the results are likely to be influenced by scale changes and perceptual biases, such as regression to the mean and serial dependence. Furthermore, our findings suggest that a reasonable level of awareness and caution should be used in the interpretation of the findings from such studies.

In order to account for the perceptual errors arising from dynamic conditions, future research would benefit from the use of a control condition where body size estimates are additionally made under static viewing conditions. Ideally, the control condition would need to simulate, as close as possible, the conditions of the dynamic experiment, but provide body size estimates under conditions that do not involve motion. For example, in tasks involving participants’ body size estimates of bodies in motion or in relation to whether they can fit through various apertures as they move through the scene, a comparative task could be
introduced where participants also estimate body size without motion, or by judging their body size in relation to the aperture prior to moving through the scene. Doing so would better position researchers to estimate and account for the amount of error that has been introduced as a result of their dynamic experimental conditions. This could lead to more accurate interpretations, which are less confounded by experimental factors.

The results of the present research provides useful information to researchers regarding the use of dynamic conditions to study body size estimations and perceptual biases. However, one limitation that must be acknowledged, is that we were not able to calculate the precise amount of perceptual error that is introduced at each stage of the scale or size changes in the dynamic body images. This is because participants in our experiment made body size judgments following a 50% decrease in the physical size of the body image. Consequently, we do not know how much error is introduced by reducing the physical size of body images by 10 or 20%, for example. In order to estimate the amount of error that is introduced across dynamic changes of various sizes, future research could obtain participants’ body size estimates after specific reductions (e.g., 10% reductions) of the physical size of the body image. Furthermore, only one rate of size change was examined (i.e., 50% reduction over 500 ms). Future research would benefit from exploring additional rates of size change by adjusting the presentation time of stimuli in combination with the reduction of image size, as mentioned above. In doing so, this would allow researchers to better estimate how much error their particular experimental designs introduce. It should also be noted that the temporal profile of the shrinking remained constant throughout the presentation of the body images. Therefore, the temporal profile could be altered in future studies (i.e., increasing blurriness of the image as it shrinks) to bolster real-world viewing conditions.
In addition to the examination of other image size changes and rates of size change, it may also be useful to incorporate a dynamic control condition, where participants judge the body size of a random dynamic sequence (i.e., a body image which moves up/down or side to side on the screen). A dynamic manipulation of this nature would not be expected to bias participants’ body size judgments. In turn, this could provide an additional control condition.

Furthermore, given the findings of the current research occurred within the context of a relatively controlled dynamic movement (i.e., linear shrinking), future research examining other aspects of dynamic movement such as dynamic changes in pose, viewpoint and biological motion, would be a logical next step in further examining body size estimation biases of dynamic bodies. If greater perceptual biases are found using these manipulations, as one might expect when the viewing conditions used to judge body size change, this would provide mounting evidence for the recommendation of control conditions in studies involving body size estimations in dynamic environments.

In summary, the current research investigated whether body size estimates are robust to, or biased by dynamic changes. Our results revealed that, compared to static body images, dynamic body images were judged to be smaller overall, consistent with use of local rather than holistic cues to determine body size. In addition, dynamic body movement appears to have increased perceptual uncertainty, as evidenced by greater body size estimation biases, owing to regression to the mean and serial dependence. The findings of the present research provides valuable information to researchers examining body image distortions in dynamic environments. In particular, our results suggest that closer consideration be given to experimental designs that involve body size estimation of dynamic body stimuli or in environments that are inherently dynamic.
5.6 References


Riva, G., & Dakanalis, A. (2018). Altered Processing and Integration of Multisensory Bodily Representations and Signals in Eating Disorders: A Possible Path Toward the


CHAPTER SIX:

GENERAL DISCUSSION
6.1 Thesis Aim and Organisation of the General Discussion

Young women with eating disorders are known to misperceive their body size to a greater extent than their healthy peers (Gardner & Brown, 2014; Keizer et al., 2013). Critically, body size misperceptions are considered to contribute to body image disturbances, a core clinical feature of eating disorders (Mohr, Rickmeyer, Hummel, Ernst, & Grabhorn, 2016). Despite this, relatively little is known about the perceptual factors that lead one to misperceive their body size, and that of others. In addition, a large amount of research is being conducted using novel experimental methods to study body size misperceptions, such as the use of computer-generated (CG) body stimuli and dynamic experimental conditions. However, there is a scarcity of literature regarding whether the use of these experimental configurations have a bearing on size estimation accuracy. Therefore, the overall aim of the thesis was to facilitate our understanding of the perceptual factors that contribute to body size misperception in healthy individuals, as well as those with, or at risk of an eating disorder. In this vein, this thesis presented two sections, each with two experimental research studies. In the first section, we revealed serial dependence in body size estimation and established its clinical relevance. In the second section, we investigated the impact of experimental factors on body size estimation and related biases. Accordingly, the General Discussion first presents a summary of the research studies in each section, in order. Next, the theoretical and practical implications of the research findings are considered, followed by a discussion regarding the limitations of the current research and future research directions. Lastly, this section ends with some final concluding remarks.
6.2 Summary of Research Findings

6.2.1 Study 1: Past Visual Experiences Weigh in on Body Size Estimation

Prior research in body size perception has identified at least two different types of perceptual bias that contribute to body size estimation errors: adaptation (occurs when perception of body size is biased away from previously viewed stimuli; Brooks, Mond, Stevenson, & Stephen, 2016; Hummel, Rudolf, Untch, Grabhorn, & Mohr, 2012) and regression to the mean (occurs when body size estimations regress toward the average body size; Cornelissen, Gledhill, Cornelissen, & Tovée, 2016). More recently, serial dependence bias (occurs when perception is biased toward prior stimuli) was discovered as a candidate process that facilitates a smooth temporal continuity to our perceptual experience (Fischer & Whitney, 2014). Serial dependence was initially discovered in the perception of number (Corbett, Fischer, & Whitney, 2011) and orientation (Fischer & Whitney, 2014) and subsequently extended to person perception related stimuli (e.g., human faces; Liberman, Fischer, & Whitney, 2014). Whether serial dependence occurs for body size estimation was previously unexplored. However, previous findings of serial dependence for other high-level stimuli (i.e., faces; Liberman et al., 2014) suggested a strong likelihood that serial dependence would also be observed in body size judgments. Therefore, the aim of Study 1 (Chapter 2) was to test for serial dependence in body size estimation.

Using the bodyline paradigm, a method established in this thesis for measuring body size estimates, it was found that participants exhibited biases toward prior visual experience, consistent with serial dependence. Furthermore, largest serial dependencies were observed for participants who were least precise in estimating body size. These characteristics were consistent with recent theoretical accounts of serial dependencies in vision and also, our data
were well fit by a recently published model of serial dependence (a Kalman-filter ideal-observer model; Burr & Cicchini, 2014; Cicchini, Anobile, & Burr, 2014; Cicchini, Mikellidou, & Burr, 2018), as predicted. Together, the selective assimilation across small, but not large, trial to trial body differences and, increased serial dependence bias under low task precision, demonstrates the sophistication of serial dependence as a process. These findings also accord with the view that serial dependencies improve measured performance by reducing perceptual noise and improving efficiency (Burr & Cicchini, 2014; Cicchini et al., 2018). In addition to measuring serial dependence in body size estimation, the bodyline task additionally revealed findings consistent with regression to the mean. Regression to the mean and serial dependence were found to be distinct perceptual processes, as evidenced by a non-significant relationship ($r(103) = -0.15, p > .05$) between the two biases. Overall, the findings of Study 1 (Chapter 2) presented the first account of serial dependence in body size estimation and introduced a novel bodyline paradigm, which additionally estimates regression to the mean biases. Having established that serial dependencies contribute to errors in body size estimation, the next study presented in this thesis assessed the clinical relevance of serial dependence bias.

### 6.2.2 Study 2: Evidence for a Perceptual Mechanism Relating Body Size Misperception and Eating Disorder Symptoms

Given the finding of serial dependence bias in body size estimation, a logical next step in Study 2 (Chapter 3) was to examine the clinical relevance of body size misperceptions due to serial dependence. Prior research indicates that individuals with eating disorders experience greater body size misperceptions (Gardner & Brown, 2014; Mohr et al., 2016). As such, it was hypothesised that serial dependence bias magnitude would be positively associated with eating disorder symptoms, as assessed by the commonly used Eating Disorder Examination
Questionnaire (EDE-Q) (Fairburn & Beglin, 1994). Partial correlation analyses were conducted between magnitude of serial dependence bias and eating disorder symptoms, controlling for body mass index (BMI). Doing so revealed a positive and significant relationship between serial dependence and eating disorder symptomatology. Put simply, young women with greater eating disorder symptoms experienced larger body size misperceptions, owing to serial dependence. Crucially, these findings implicate serial dependence as a clinically relevant bias in the context of body size estimation errors. The correlational findings in this study were critical in extending previous literature on body image distortion (e.g., Cornelissen, Bester, Cairns, Tovée, & Cornelissen, 2015; Gardner & Brown, 2014; Mohr et al., 2016), by providing evidence that distorted serial dependence processes contribute to the exaggerated misperceptions seen in those with an eating disorder.

In addition to assessing the clinical relevance of serial dependence, an additional aim of the study was to shed light on the stage of visual processing in which serial dependence occurs. To do so, an inversion paradigm was employed, common in other areas of research such as face processing (Farah, Tanaka, & Drain, 1995; Feusner et al., 2010; Freire, Lee, & Symons, 2000), for assessing whether perception or performance utilises specific visual features (e.g., in this case, thigh width) or involved more holistic information (e.g., hip-to-waist ratio). The finding of a significant difference in serial dependence between inverted and upright bodies would imply that serial dependence occurs higher in the perceptual hierarchy, at the holistic body processing level (Reed, Stone, Bozova, & Tanaka, 2003). Instead, the results of this study revealed no inversion effect for serial dependence bias in body size estimation. This indicated that distortions in low-level local visual features (e.g., hip width), rather than high-level holistic attributes (e.g., whole bodies), can adequately explain serial dependence in body size.
estimation. The finding of a correlation of eating disorder symptoms with a low-, rather than high-level perceptual bias is discussed in further detail below, within the context of weak central coherence and cognitive inflexibility. In sum, the first section of this thesis established the existence of serial dependence bias in body size estimation, and demonstrated its clinically relevance. The second section of this thesis then sought to determine whether body size estimates and errors are robust across typical changes in experimental conditions.

6.2.3 Study 3: An Assessment of Computer Generated Stimuli for Use in Studies of Body Size Estimation and Bias

The aim of the second section of this thesis was to consider how experimental conditions might impact body size estimation and related biases, namely serial dependence and regression to the mean. One emerging development in the field of body size perception is the use of CG body stimuli in size estimation tasks. The use of CG stimuli has permitted substantial advances in the study of body size estimation as this stimulus type offers greater parametric control over the systematic manipulation of body size characteristics, and is time efficient in comparison to the acquisition of real body images (Moussally, Rochat, Posada, & Van der Linden, 2017). However, research in face perception indicates that CG face stimuli are more poorly recognised, in comparison to real faces (Balas & Pacella, 2015; Crookes et al., 2015). One of the explanations put forward is that CG stimuli compromise the salience of textural features used to judge faces (Crookes et al., 2015). With this research in mind, it seemed sensible to consider whether CG body stimuli can be used interchangeably with real body images, or whether CG procedures similarly compromise the appearance of key textural features used to judge body size, such as cellulite. As such, the purpose of Study 3 (Chapter 4)
was to investigate the efficacy of using CG body images in studies of body size estimation and bias.

The findings from Study 3 revealed poorer body size estimations for CG bodies. That is, participants struggled to discriminate between extreme CG body sizes and overestimated the size change between near average bodies. This finding was demonstrated by a non-linear pattern of judgments for CG body sizes. In addition, and as predicted, poorer discrimination of the CG bodies led to greater serial dependence, in comparison to prior estimates of serial dependence for real body stimuli in Study 1 (Chapter 2). Finally, in this study, eating disorder symptoms, as measured by the EDE-Q, were not found to be significantly associated with serial dependence bias for CG bodies. This was in contrast to our previous finding in Study 2 (Chapter 3), of a significant relationship between serial dependence bias and eating disorder symptoms. It was argued that the use of CG bodies might have reduced social comparisons between the participant’s own body shape and the body images, and consequently, diminished the meaningful individual differences in the observed serial dependence. Together, these findings indicated that CG bodies are more poorly discriminated than real equivalents, likely because the CG algorithms compromise the representation of key visual features (e.g. cellulite or noticeable emaciation), which are important for making body size judgments, particularly for extreme body sizes. Accordingly, the results of this study suggested that caution should be used when employing CG body stimuli in the study of body size estimation and bias. In the final study below, the use of dynamic conditions was considered.
6.2.4 Study 4: Body Size Estimation Errors Increase for Dynamic Presentations

In addition to the increased use of CG body stimuli, researchers are increasingly creating dynamic settings (e.g., involving self or other movement) to study body size misperceptions (e.g., Keizer et al., 2013; Vocks, Legenbauer, Ruddel, & Troje, 2007). Again, the consequences of adding dynamic movement to body image related experiments were previously unexplored. As such, Study 4 (Chapter 5) sought to examine whether body size estimates and associated perceptual biases, are robust under dynamic experimental conditions, such as when the to-be-judged body appears to move away from the observer.

The results of this study showed that dynamically contracting body images were predominantly judged to be smaller than static equivalents. This finding demonstrated that body size estimates were not robust under dynamic conditions, but rather, were influenced by the scale change of the body images. In addition, this result indicated the use of local (e.g., thigh width) rather than holistic (e.g., hip-to-waist ratio) cues to determine body size, since the use of holistic or ratio based cues would predict constancy in body size estimates, while the use of single features would not. This finding of local cue use was also consistent with the inversion experiment results in Study 2 (Chapter 3). A second, important piece of insight provided in this study was the finding that adding dynamic change to the body stimuli increased our two measured perceptual body size estimation biases, regression to the mean and serial dependence. This finding appeared to reflect the consequence of increased stimulus uncertainty in the dynamic condition. The combined findings of Study 4 were in line with the conclusions made by Study 3, that modifications to visual cues through the use of CG bodies or dynamic contraction, can alter body size estimates and increase body size misperceptions.
6.3 Theoretical Implications of the Combined Findings

As a collective, the first section of this thesis contributed valuable evidence regarding the perceptual biases that contribute to body size estimation errors in healthy individuals, as well as those with an increased risk of developing an eating disorder. Accordingly, these findings are discussed below as providing critical insights to the theoretical accounts of body size biases in an eating disorders context and the relation between body size misperception biases, more broadly.

6.3.1 The Clinical Relevance of Serial Dependence Bias

The first section of this thesis established serial dependence as a source of bias in body size estimation and demonstrated its clinical relevance in an eating disorders context. As such, these empirical findings are discussed here as providing critical insight to the theoretical understandings of body size biases and eating disorder theories, cognitive inflexibility and weak central coherence.

As previously summarised, Study 2 (Chapter 3) demonstrated a positive association between serial dependence and eating disorder symptoms. One way of considering the observed association between serial dependence and eating disorder symptomatology is through the lens of cognitive inflexibility. Cognitive inflexibility is a neurocognitive deficit that is observed when individuals display difficulties in their ability to adapt to changing situations or flexibly switch between tasks (Perpina, Segura, & Sanchez-Reales, 2017). Recent empirical findings have revealed that cognitive inflexibility is a feature that is typical of the neuropsychological profile of individuals with eating disorders (Tchanturia et al., 2012; Tchanturia et al., 2011). As this thesis and other research shows (Burr & Cicchini, 2014; Cicchini et al., 2014; Cicchini, Mikellidou, & Burr, 2017; Fischer & Whitney, 2014), serial
dependence relies on continual updating over time, as perception of current visual information becomes the next iteration of prior visual information. Individuals with eating disorders are known to struggle with sustained and distorted representations of their bodies (American Psychiatric Association, 2013). Given this, and the importance of updating in serial dependence, the relationship between greater serial dependencies in individuals higher in eating disorder symptoms (Study 2, Chapter 3) appears to reflect a perceptual inflexibility to update visual information regarding body size, and leading to overuse of prior information; i.e. greater serial dependence. This is consistent with empirical findings of cognitive inflexibility in individuals with eating disorders (Tchanturia et al., 2012; Tchanturia et al., 2011). Together, this suggests that individuals who display cognitive rigidity, common in those with eating disorders, are more vulnerable to experiencing greater serial dependencies. However, as the two processes reflect two distinct mechanisms, perception and cognition, and cognitive inflexibility was not directly examined, future studies would be required to establish their shared relationship, if any, prior to making solid inferences regarding the nature and extent of this correlational finding.

A complimentary theory regarding why individuals with eating disorders might be vulnerable to exaggerated serial dependence biases relates to weak central coherence. As outlined in Study 2 (Chapter 3), weak central coherence is a cognitive processing style that is characterised by the processing of local detail-oriented information to the detriment of global holistic integration (Lang, Lopez, Stahl, Tchanturia, & Treasure, 2014). Crucially, individuals with eating disorders have been shown to process information in a piecemeal fashion, consistent with superior local, rather than global processing; i.e. a weak central coherence (Kanakam, Raoult, Collier, & Treasure, 2013; Lang et al., 2014). In the context of body image,
those high in eating disorder symptomatology, or with diagnosed eating disorders, have also been shown to become selectively fixated on specific visual features relating to their bodies (Jansen, Nederkoorn, & Mulkens, 2005; Tuschen-Caffier et al., 2015). For example, in a study conducted by Tuschen-Caffier et al. (2015), young women with eating disorders were shown to selectively attend to their own self-reported ‘ugly’ body parts more frequently, than their self-reported ‘beautiful’ body parts, when viewing their bodies in a mirror. In contrast, healthy controls displayed more balanced patterns of attention on their bodies (Tuschen-Caffier et al., 2015). This featural attention on disliked body parts seems to not only serve as an information processing bias that feeds into the further dislike of body parts, but also appears largely consistent with research that shows dominant local processing in those with eating disorders (Lang et al., 2014). Critically, in a different study conducted by Urgesi et al. (2014), individuals with diagnoses of anorexia nervosa displayed a deficit in their holistic processing of bodies. The authors theorised that this was reflective of their processing style, which is characterised by a detail-oriented focus on body parts (Urgesi et al., 2014). On face value the reports of local processing preferences in these individuals appears to accord with our findings in Study 2 (Chapter 3), of an association between eating disorder symptoms and a bias that is driven by the processing of local visual features. Although speculative, this suggests that weak central coherence in those with, or at risk of developing eating disorders, could provide a theoretical framework for understanding why these individuals are at risk for exaggerated serial dependence biases. However, given the present research did not measure central coherence, a direct investigation of the relationship between serial dependence bias, weak central coherence and eating disorder symptomatology would be required to provide a better indication of a possible association.
In summary, the findings of Study 2 (Chapter 3) suggest that individuals with inflexible processing styles, such as those with elevated eating disorder symptoms, are prone to inflexible perception leading to larger serial dependencies. Further, these results also suggested that those with greater local detail-oriented processing are vulnerable to exaggerated serial dependencies. Together, these findings appear consistent with theories of cognitive inflexibility and weak central coherence in an eating disorder context. However, given that no direct markers of these two cognitive processes were measured, a follow up study/s investigating the relationship between these processes and serial dependence, seems prudent. Having now discussed the theoretical accounts of our findings, the section below considers how the known perceptual biases in body size estimation relate to one another.

### 6.3.2 Assessing the Relationship Between the Three Perceptual Sources of Body Size Estimation Bias

Adaptation and regression to the mean biases have been established in the literature as contributing to body size estimation errors (Brooks et al., 2016; Cornelissen et al., 2016; Mohr et al., 2016). In this thesis, serial dependence was demonstrated as a third bias contributing to body size misperceptions. As such, there are now at least three known perceptual biases that have been shown to occur for body size estimation; adaptation, regression to the mean, and serial dependence, the latter two of which were measured and estimated in this thesis. This positions body size perception as an ideal process with which to consider if and how these three biases are related. The answer to this question also has relevance for vision more generally, not just for the field of body perception. Accordingly, the results of the first section of this thesis are considered in terms of relating serial dependence with regression to the mean and adaptation biases.
Given the bodyline paradigm developed in this thesis measured both serial dependence and regression to the mean biases, this allowed for the consideration of the direct relationship between serial dependence and regression to the mean biases. However, as this task did not measure adaptation, and no other research has directly assessed the relationship between serial dependence and adaptation in the context of body size estimation, the relationship between these biases are discussed with regards to published findings in the broader literature.

Turning first to the relation between serial dependence and regression to the mean, the first section of this thesis (Study 1, Chapter 2) revealed that serial dependence and regression to the mean biases were not significantly related in the context of body size estimation (r(103) = -0.15, p > .05). This result indicated that regression to the mean and serial dependence biases are effectively independent processes that simultaneously occur within the perception and estimation of body size. This result diverged from previous research which has suggested that serial dependence and regression to the mean are related processes within the perception of visual number (Cicchini et al., 2014). One obvious explanation for this discrepancy is that the presence or absence of a relationship between these two processes is dependent upon the specific visual process being activated by the task. Evidently, further research is required in order to better understand the relation between these biases. One apparent starting point for future work would be to test the relation between these biases across other visual processes in order to provide a better consensus on if, and when, these biases are related.

Switching focus to the relationship between serial dependence and adaptation bias, both of these biases reflect a distortion induced by the prior stimulus. However, research is yet to clearly resolve how these two biases operate in opposing fashion. As adaptation was not directly measured in the current research, and is typically observed in separate paradigms (i.e.,
with slow sequences of adaptors) from that of serial dependence (i.e., involving rapid presentations of stimuli), the relation between this bias and serial dependence is first considered more broadly using recent work in the broader perception literature. This discussion is then related back to the context of body size perception.

Recent conjecture about whether serial dependence is a perceptual bias or a decisional bias had been put forward to explain its relation with adaptation, which is generally agreed as perceptual (although see: Storrs (2015)). In particular, Pascucci et al. (2019) who examined the relation between serial dependence and adaptation biases across several perceptual orientation judgment tasks, suggested that serial dependence occurs across perceptual decisions, but not on the appearance of the stimulus. Whereas, adaptation biases were suggested to act directly on perceptual stimuli, repulsing perception away from prior sensory input (Pascucci et al., 2019).

Although an abridged summary, the authors compared stimulus-driven biases and response-driven biases in orientation perception. They did so by interleaving observer responses regarding the orientation of stimuli, with sequences of orientations, which observers did not respond to (Pascucci et al., 2019). Their findings revealed that serial dependence biases occurred relative to the previous response made, rather than to the previous stimulus (Pascucci et al., 2019). The authors indicated that this provided evidence that serial dependence emerges from high-level decisional processes (Pascucci et al., 2019). These findings by Pascucci et al. (2019) and that of several other studies (Czoschke, Fischer, Beitner, Kaiser, & Bledowski, 2019; Fritsche, Mostert, & de Lange, 2017), suggest that adaptation and serial dependence biases are separable processes occurring at different levels of the processing hierarchy, with adaptation suggested to occur at the low-level perceptual stage of visual processing and serial dependence suggested to occur at a high-level decisional stage.
Crucially, the findings by Pascucci et al. (2019) and others, diverge from the broader serial dependence literature that indicates serial dependence as a process that occurs early in visual processing, at the perceptual stage, and not arising as a decisional process (Fischer & Whitney, 2014; John-Saaltink, Kok, Lau, & de Lange, 2016; Kim, Burr, & Alais, 2019; Manassi, Liberman, Kosovicheva, Zhang, & Whitney, 2018). The results in this thesis, and other prior literature regarding serial dependence are discussed below as providing support for a perceptual account of serial dependence. Weighing into the perceptual vs. post-perceptual account of serial dependence is paramount to answering the broader question regarding the relation between serial dependence and adaptation.

One of the first pieces of evidence in favour of a perceptual account for serial dependence arises from neurobiological evidence. In the first instance, a study conducted by John-Saaltink et al. (2016) used functional magnetic resonance imaging (fMRI) to examine serial dependencies in the primary visual cortex during a perceptual orientation judgment task. Behavioural results of their task revealed that reported orientation was biased toward prior orientations, consistent with serial dependence. Furthermore, this serial dependence bias was spatially specific, occurring for orientation seen in similar locations and not for those in which the location varied, seemingly excluding a simple decisional explanation of this bias. Furthermore, activation patterns in the primary visual cortex (V1), as measured using fMRI, showed evidence of the bias towards orientations shown in the preceding trial (John-Saaltink et al., 2016). This vital piece of evidence indicated that serial dependence can be seen in the patterns of V1 activation, implying a strong low-level perceptual account of this bias, occurring early in visual perception. Within the context of body size estimation, serial dependence was
also demonstrated as a low-level bias, arising prior to holistic integration (Study 2, Chapter 3), consistent with the findings by John-Saaltink et al. (2016).

Further, a recent study by Fornaciai and Park (2018) also proposed a perceptual account of serial dependence based on their observations that serial dependence occurred in the absence of an explicit task requiring judgments of stimuli (i.e., decisional processes). Importantly, a finding of this nature suggests the involvement of early stages of perceptual processing in serial dependence and provides support for a perceptual account of serial dependence. Similarly, in other research experiments that dissociated stimuli from responses, serial dependence was found to primarily act on the stimulus, rather than the decisional responses made about it (Cicchini et al., 2017). In addition, a recent face perception study by Turbett, Palermo, Bell, Burton, and Jeffery (in press) who replicated the interleaved trials of the Pascucci et al. (2019) study, showed strong serial dependence in response to prior stimuli, not to responses (Turbett et al., in press). It is important to note, that while the findings here, and that of the majority of research (e.g., Cicchini et al., 2017; Fischer & Whitney, 2014; Fornaciai & Park, 2018; John-Saaltink et al., 2016) provides a strong perceptual account of serial dependence, the effect that post-perceptual processes might have on this bias, small as they may be, cannot be discounted.

Drawing the collective findings together, it is evident that the relationship between serial dependence and adaptation is far from settled. A contributing source of this ambiguity stems from the diverging findings regarding the nature of serial dependence, as outlined above. Given the varied findings relating to the nature of serial dependence, it is possible that serial dependence, similar to regression to the mean, operates differently for varying visual processes. If this is the case, then it would not be surprising that the relation between serial
dependence and adaptation also differs across different visual processes. This might be the case for body size estimation, given serial dependence has now been shown to operate on low-level visual cues relating to bodies (Study 2, Chapter 3) and body adaptation has been established as a high-level perceptual bias (Brooks, Clifford, Stevenson, Mond, & Stephen, 2018). Clearly, research moving forward would greatly benefit from better elucidating whether serial dependence is a singular common process, or differs across visual processes. As the findings of this thesis established serial dependence as one source of bias in body size estimation, body size perception, represents an ideal model with which to continue this investigation.

Overall, the combined findings from this thesis provided critical insights regarding the relation between serial dependence and regression to the mean in body size estimation. By incorporating the broader perception literature, the relation between serial dependence and adaptation biases were also considered, but the interpretation here is far from settled. As the relationship between adaptation and regression to the mean biases has yet to be considered in the broader literature, the relation between these biases also remains unclear and cannot be discussed here. We would note however, that resolving the relationship between serial dependence and adaptation would shed significant light on this question. That aside, this discussion provides a basis with which to extend our theoretical understanding regarding the relationship between serial dependence, regression to the mean and adaptation biases.

6.4 Practical Implications of the Combined Findings

The preceding sections provided important insight into the theoretical underpinnings of serial dependence biases in a clinically relevant context, and more broadly considered the relation between three biases known to occur in body size misperceptions: serial dependence, regression to the mean, and adaptation. Next, the combined results of the second section of the
thesis are discussed as contributing to two important practical implications. That is, the
importance of considering the body stimuli and experimental factors employed in body size
perception research. These practical implication are considered together, in the section below.

6.4.1 Consideration of Stimuli and Experimental Factors in the Study of Body
Size Perception and Associated Biases

The combined findings of the second section of this thesis (Studies 3 and 4, Chapters 4
and 5) offer several practical suggestions regarding the study of body size perception and
associated biases. To recap, Study 3 revealed that, relative to real body images, the use of
computer-generated (CG) bodies led to non-linear estimations of body size and increased body
size biases owing to serial dependence. Similarly, Study 4 found that, compared to static
equivalents, the use of dynamically shrinking body stimuli resulted in smaller overall body size
estimates and increased biases due to regression to the mean and serial dependence. Together,
these findings highlight the need for careful stimulus selection and consideration of
experimental factors when designing studies of body size perception.

Regarding the use of CG body stimuli, the current findings suggest that traditional CG
body stimuli may not be an optimal stimuli choice in studies of body size estimation and bias,
and instead advocate for stimuli choices that better represent key body weight markers (e.g.,
visible bones in severe emaciation). For example, recent research has begun to incorporate the
use of ‘hybrid’ body stimuli (Stephen, Sturman, Stevenson, Mond, & Brooks, 2018). This
stimulus type involves obtaining photographs of participants’ bodies wearing standardised
clothing, under controlled conditions (e.g., lighting, background, photography angle).
Following this, these images are then manipulated across over a hundred body weight
landmark points to create realistic body size changes (Stephen et al., 2018). These stimuli seem
advantageous, as they use real body images, which are ecologically sound, while also succeeding in creating realistic body size changes using individual participant photographs.

Another recent development is in the use of 3D CG body avatars (Cornelissen, McCarty, Cornelissen, & Tovée, 2017; Molbert et al., 2018; Thaler et al., 2018). This stimulus type involves scanning participants’ bodies using 3D body scanning equipment, which creates a computerised ‘mesh’ of the participants’ bodies, which are then used to create personalised CG body avatars (Cornelissen et al., 2017). Again, this seems to better simulate real body images, as the body avatars are modelled directly from real body equivalents. Finally, three-dimensional virtual reality body stimuli may represent an alternative to traditional CG methods (Keizer, van Elburg, Helms, & Dijkerman, 2016; Serino, Polli, & Riva, 2019). Although these stimuli are synthetic in nature, they seem likely to enhance the realism associated with real body images, by better highlighting key body weight markers (e.g., stomach or thigh volume) through their three-dimensional representation. Given the disadvantages associated with traditional CG body stimuli, the findings of this thesis would advise the use of real body stimuli or a hybrid real and CG bodies (Cornelissen et al., 2017; Stephen et al., 2018), as described above. Of course, with the rapid advancements of technology, these recommendations may change in the future. Moving forward however, future research would benefit from first understanding the ecological validity associated with each of these CG body alternatives.

Regarding the application of dynamic body stimuli in experimental settings, the results of Study 4 (Chapter 5) indicated that dynamic body changes increased body size judgment errors. This finding is particularly important given the increased measurement of body size judgments in environments that are inherently dynamic (e.g., in settings involving observer or
stimulus motion; Gaudio, Brooks, & Riva, 2014; Keizer, Engel, Bonekamp, & Van Elburg, 2018; Keizer et al., 2013; Vocks et al., 2007). As such, the results of the current research suggest that future research should attempt to account for the perceptual errors occurring due to dynamic experimental factors by incorporating the use of a control condition (e.g., static equivalent) where possible. This would help researchers to quantify the specific errors they have introduced due to their experimental design, and accordingly, to account for this error when analysing and interpreting the results from these studies. Furthermore, the current research suggests that caution should be used when interpreting the findings from studies which currently do use dynamic body stimuli or in experimental settings which are dynamic in nature (e.g., require judgment of one’s own body when moving through aperture openings; Keizer et al., 2013), as they may overestimate distortions.

Together, the research presented in the second section of this thesis demonstrated the volatility of body size judgments under varying experimental conditions, and accordingly, advocates caution in using traditional CG stimuli and in the transition to dynamic environments. Furthermore, the findings offer practical suggestions by proposing the use of stimuli that better permit key body weight markers, such as in the CG alternative options described above, and in the suggestion of control conditions in experiments of a dynamic nature.

6.5 Thesis Limitations and Future Research Directions

While the studies presented in this thesis contribute valuable information towards a greater understanding of the perceptual factors involved in body size misperceptions, and their clinical and functional relevance, there are several limitations which must be acknowledged.
These limitations are discussed below and in this process, several suggestions for future research are proposed in order to address these drawbacks.

### 6.5.1 Difficulties in Creating Exemplars of All Body Size Categories and Measurement of Regression to the Mean

The first potential limitation relates to the body stimuli used in the studies presented in this thesis. In particular, the physical weight of the real and CG body stimuli were not known. Instead, the body stimuli used throughout the current research were pre-validated (see: pilot studies in Studies 2 and 4, Chapters 3 and 5) via inter-rater agreement between participants on category assignment. This task produced seven perceptually distinct body size categories, ranging from extremely thin to extremely large. Therefore, it was along the body size continuum that regression to the mean and serial dependence biases were evaluated against and a measurement made, not physical weight. Prior research (e.g., Cornelissen et al., 2016) that has used body stimuli for which the physical weight is known, have been able to quantify the precise amount of regression to the mean in their sample. Evaluating regression to the mean and serial dependence biases along body weight dimensions would, of course, provide more precise and less subjective estimates of the differences between real and perceived body size judgments. In turn, this would have permitted a precise estimate of the physical magnitude of regression to the mean and serial dependence biases in our participant data. Despite this concern, it is important to note that the regression to the mean estimates produced by the stimuli used in this thesis were near identical to the estimates produced by other studies, using stimuli with known weights (Cornelissen et al., 2016). Nonetheless, future research would benefit from extending the findings of this thesis using body stimuli for which the body
weights are known, such as those used by Cornelissen et al. (2016). This would, in turn, allow for more precise estimates of measured bias.

In addition to examining regression to the mean bias across body stimuli for which the weights are known, another important avenue for future research would be to establish whether observation of regression to the mean bias is task-dependent. The literature employs a wide variety of tasks and paradigms in the study of body size misperceptions. For example, some tasks require participants to judge body size in the presence of bodily anchors that define the scale of judgement, whereas other tasks do not contain such anchors (Cornelissen et al., 2015; Cornelissen et al., 2016; Cornelissen et al., 2017). Interestingly, several of these past studies have found varied results regarding the presence of regression to the mean bias in their task. In particular, a prior study conducted by Cornelissen and colleagues (2017) which used a method of adjustment paradigm that contained anchors, did not find a regression to the mean bias in body size estimation. However, in the same study, a similar unanchored task did detect this bias (Cornelissen et al., 2017). In contrast, the work of this thesis used a bodyline paradigm which contained anchors, and yielded similar findings regarding the presence of regression to the mean, as in Cornelissen et al. (2016), using an anchored task. Evidently, further research is required to establish the extent to which regression to the mean bias is task-dependent, and the paradigms that most accurately measure this bias. In turn, this would allow experimenters of body size misperceptions to be aware of the paradigms that produce regression to the mean bias, and account for it, if it does.

6.5.2 The Use of Other vs. Own Body Stimuli

A second consideration regarding the body stimuli used in this thesis relates to the use of other, not own, body stimuli. The present research made inferences between body size
misperceptions of others’ bodies and the perceptual component of body image disturbance. However, it is acknowledged that this presents one half of the story. This is because individuals with body image disturbance have been suggested to experience distortions and misperceptions of body size more strongly, or differently for their own body, vs. others’ bodies (Sand, Lask, Høie, & Stormark, 2011; Thaler et al., 2018). Other research emphasises that the perception of one’s own body to others’ bodies is transferable across identities (Brooks et al., 2016; Hummel et al., 2012), indicating that stimuli of own and others’ bodies tap similar visual processes. It would seem sensible then to evaluate whether serial dependence biases are larger for own-versus other bodies, particularly in individuals with, or at risk of developing, an eating disorder.

6.5.3 Examination of New Technologies in Computer-generated Body Stimuli

A final consideration regarding the body stimuli used in the present research was that the CG body stimuli used in Study 3 (Chapter 4) were created using Poser version 11 software. It is acknowledged that since the creation of our body stimuli, updated versions of the software have become available, which might better simulate anatomical details and bodily features to those of real bodies. Furthermore, as highlighted in both Study 3 (Chapter 4) and in Section 6.4.1, other CG methods are also being utilised in current research examining body perception. In particular, new methods are incorporating the use of hybrid body stimuli, which involve controlled body size manipulations in real body imagery (Stephen et al., 2018), 3D body avatars (Cornelissen et al., 2017) and the use of virtual reality technology (Ferrer-Garcia et al., 2017). Therefore, while the research in Study 3 presents a clear picture for poorer discrimination in body size judgments of CG body stimuli, it is acknowledged that these interpretations are limited to the software used in the present research. Future studies would
greatly benefit from understanding how these new CG technologies affect body size judgments and whether they better simulate the bodily regions of real bodies.

### 6.5.4 Lack of Diversity in a University Participant Sample

Each of the research studies presented in this thesis comprised a young adult female sample between the ages of 17 to 25. This sample was chosen because eating disorder diagnoses have been shown to be highly prevalent in this population (The Butterfly Foundation, 2012), making the young female population an imperative sample for studying body image related phenomena. Given this, and the main purpose of this thesis – to contribute to our understanding of the perceptual factors involved in body size misperceptions – it was important to first establish whether the perceptual factors of interest exist at baseline levels (i.e., in a healthy, but highly relevant population) prior to investigating how these processes might differ in a more specific interest group (i.e., those with eating disorder symptoms or with eating disorder diagnoses). Nonetheless, the research in this thesis predominantly comprised undergraduate university students, not clinical populations. University samples can often be skewed in terms of age, BMI and eating disorder symptoms, all of which are important variables in an eating disorders context (American Psychiatric Association, 2013; The Butterfly Foundation, 2012). An important consideration then, is whether, and how, the serial dependence bias observed in the current research differs in community samples that comprise a broader representation of these important variables, and vitally, in an eating disorder context.

The results from Study 2 (Chapter 3) demonstrated the clinical relevance of serial dependence. Therefore, a logical next step would be to examine serial dependence with a clinical eating disorder sample. Doing so could help to elucidate whether altered serial dependence bias contributes to the exaggerated perceptual body image disturbances seen in
those with eating disorders. This could be tested by comparing serial dependence magnitude on the bodyline task between a clinical and healthy control group. Although somewhat preliminary, the finding of larger serial dependencies in those with greater eating disorder symptoms (Study 2) leads to a prediction that the clinical group would exhibit greater serial dependencies, compared to the control group. Assuming this is the case, this could lead to future developments in the bodyline paradigm for measuring perceptual body size estimation errors in clinical settings. This could be particularly useful within a diagnostic context, given clinicians currently tend to identify body image disturbance symptoms via client self-report, and through the use of questionnaire measures of body image disturbance (Bolton, Lobben, & Stern, 2010; Mitchell & Peterson, 2005).

6.5.5 Consideration of Sex and Race Characteristics in Body Size Perception

Another potential limitation related to the sample characteristics of the current research is that male participants were not assessed. The studies presented in this thesis reported on the perception of female body size from young women observers, due to the high prevalence of eating disorders in this sample (The Butterfly Foundation, 2012). However, emerging research has identified that eating disorders are increasing in male populations too (Strother, Lemberg, Stanford, & Turberville, 2012). Accordingly, it would be useful to extend the findings presented in this thesis to a male population, using male body related stimuli. Recent research suggesting the males gravitate toward muscular ideals (Dondzilo, Rodgers, Turnbull, & Bell, 2019) indicates that the continuum for investigating male body image ideals incorporates muscle dimensions, not just fat dimensions. In fact, there is evidence that body muscle and fat are separable dimensions (Sturman, Stephen, Mond, Stevenson, & Brooks, 2017), and emerging evidence has also demonstrated some neural separation in the processing of body
size perception of male and female bodies (Brooks, Baldry, et al., 2019; Brooks, Keen, et al., 2019). Accordingly, future research examining serial dependence in males would benefit from employing male stimuli that vary in muscularity. While there is an expectation that serial dependence biases would similarly occur for males, since serial dependence is a widely observed phenomena, it would be of interest to examine whether individual differences in eating disorder symptoms and magnitude of serial dependence present similarly in a male sample.

In addition to exploring serial dependence along the male continuum of body size, future research may benefit from investigating serial dependence in the context of the race of bodies. Recent research in this area of body perception has been conducted using an adaptation paradigm (Gould-Fensom et al., 2019). In doing so, the authors discovered that adaptation aftereffects transfer across the races of bodies (Caucasian and Asian). This indicated that body size is encoded through an ethnicity-general neural mechanism (Gould-Fensom et al., 2019). Investigating this area using a serial dependence paradigm might assist in clarifying whether serial dependencies occur in this context of body perception, and further elucidate the neural mechanisms involved in the perception of body size and ethnicity.

### 6.5.6 Consideration of the Time Course of Serial Dependence

An additional important consideration of future research regards the investigation of time course. In the present research, serial dependence was investigated across a rapid time course (i.e., seconds) in line with prior literature (e.g., Cicchini et al., 2014). A large majority of research in serial dependence has shown a reduction of serial dependence bias over time (e.g., Fischer & Whitney, 2014; Liberman et al., 2014; Manassi et al., 2018). However, there is some emerging research that has also demonstrated serial dependencies in
longer time courses too (e.g., tens of minutes; Gekas, McDermott, & Mamassian, 2019).

Elucidating whether serial dependence in body size estimation occurs in shorter or longer time periods and in clinical samples diagnosed with eating disorders, as outlined above, could assist in identifying the real world contexts in which serial dependence in body size estimations are most likely occur. Furthermore, testing whether serial dependencies build up and are cumulative across longer time periods (e.g., years) could further determine potential contributions to eating disorder symptoms. Nonetheless, based on the majority of serial dependence literature, which shows that serial dependence bias does diminish across shorter time periods (e.g., Fischer & Whitney, 2014), we might expect a similar finding in the context of body size estimation. If this is the case and there is a significant relationship between serial dependence and eating disorders, the serial dependence bias might account for misperceptions seen in contexts where brief body size judgments are made, such as looking at oneself in the mirror, or judging others’ body size as one moves through a crowd.

### 6.5.7 Consideration of Other Perceptual Factors Involved in Body Size Estimation

The current research measured body size estimation errors within the context of serial dependence and regression to the mean biases, and through the primary sense of vision. However, it is acknowledged that there are additional perceptual biases which have not been measured in the present research, such as adaptation biases (Brooks et al., 2016) and Weber’s law (i.e., difficulty in detecting increases in body weight as it increases; Cornelissen et al., 2016), which are have also been shown to contribute to body size estimation errors. Research examining these various body size biases are increasing. However, research regarding the relation between these body size biases are scarce. In order to build a clearer picture of
perceptual body image disturbances, future research studies would benefit from examining the association between each of these biases, and their contribution to distortions of body size. Furthermore, the present research examined body size perception biases within the visual domain. Prior work has revealed that individuals with eating disorders experience perceptual body image disturbances across other perceptual domains too (e.g., tactile, proprioception, motion) and in the integration of these multisensory experiences (Gaudio et al., 2014; Keizer et al., 2013; Riva & Dakanalis, 2018). Extending the examination of serial dependence in body size estimation to domains other than vision may provide critical insights regarding the contribution of this bias to the broader perceptual body image disturbance phenomenon.

6.5.8 Involvement of Attitudinal Factors in Body Size Perception

A final limitation that should be acknowledged of this thesis is that attitudinal factors of body image disturbance (i.e., one’s desired body size or weight) were not directly examined in relation to the body size misperceptions observed in this thesis. Research in this area has found diverging results regarding the relation between attitudinal and perceptual components of body image disturbance. For example, some research proposes that body image disturbances are driven by attitudinal factors (Mölbert et al., 2018), while other studies emphasise the importance of perceptual factors (Cornelissen et al., 2015; Dakanalis et al., 2016). In order to build a comprehensive model of body image disturbance, it will be important to clarify the relationship between attitudinal components of body image disturbance with perceptual distortions of body size (adaptation, regression to the mean and serial dependence). In turn, this could extend theoretical understandings of the role of each component in contributing to the broader phenomenon of body image disturbance.
6.6 Final Conclusions

To conclude, the first section of this thesis demonstrated that young women experience body size misperceptions due to serial dependence biases. Critically, in Study 2 (Chapter 3) young females with elevated eating disorder symptoms were found to experience greater body size misperceptions owing to serial dependence, demonstrating the clinical relevance of serial dependence biases. The second section of this thesis showed that body size estimates are susceptible to, and altered by, changes in experimental conditions, via the use of CG body stimuli and under dynamic circumstances. Collectively, the findings presented in this thesis offered important insight for understanding the nature and extent of body size misperceptions in an eating disorders context, a broader understanding of the relation between perceptual phenomena contributing to body size estimation errors and practical implications regarding the development of sound body stimuli in studies of body size perception.
6.7 References


doi:10.1111/bjop.12057

doi:10.1002/eat.20336