

THE ACCURACY AND STABILITY OF BODY REPRESENTATION

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ABSTRACT

How we perceive our bodies and how the body is represented in the brain is not yet fully understood. We need accurate information about our bodies in order to interpret and react to sensory information that is constantly being received and that is coded relative to our body. My dissertation aims to understand how the body is perceived and represented in the brain by exploring the accuracy and stability of body representation. I developed a novel two-alternative forced choice adaptive staircase psychophysical method to determine how accurate people are in judging real and distorted life-size images of their body. Participants were sequentially shown two life-size images of their body (one interval containing the undistorted image and one interval containing the distorted image) and had to report which image most closely matched their own perception of their body size. Width and length dimensions were distorted separately. The image was also presented in different orientations (such as upright, right, left, and upside down) in order to assess how accuracy perception changes when the image is presented in familiar and unfamiliar views. Four separate experiments were conducted to test perceived size for: 1) the face, 2) the arm, 3) the hand, and 4) the full body. The goal of these studies was to measure accuracy in different orientations, for both the width and length dimensions, to obtain baseline values of how distorted the brain's representation of various body parts are. I demonstrated that there are distortions in perceived size and that factors such as body part, orientation, sex, and body satisfaction impacted accuracy. To explore the nature and extent of the brain's plasticity and flexibility, I investigated how manipulating body representation affects body perception and whether accuracy values can be changed. Manipulating body representation using both visual and vestibular methods resulted in changes to perceived body size accuracy. These results

provide insights into how the brain represents the body, revealing that body size perception is flexible and plastic.

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CHAPTER 1:
General Introduction

The body is essential in everything we do – without it, we would not even exist – so therefore, it is critical that our brain is accurately able to represent our bodies in all situations especially those involving perception and action. How the brain represents the body is a challenge to investigators because the experience of the body requires multisensory processing in multiple cortices of the brain. Many aspects of perception and action require that immediate sensory signals be combined with stored representations of body size and shape. If we do not have an accurate representation of the properties of our body, how can we properly function in the world? In this dissertation, I set out to measure the accuracy and stability of the brain's representation. Traditionally, the study of body perception has been examined from single discipline viewpoints –for example, clinical scientists typically focus on eating disorder populations to study the concept of body image, whereas behavioural/cognitive/brain research attempts to address body perception from the focus of how the body is represented in the brain. Approaching research from a specialized viewpoint with a specific goal in mind – for example developing treatments for eating disorder patients - lacks the multidimensional perspective that is required to understand the normal representation in the brain.

Our body representation may have innate origins due to the motor and somatosensory systems but incorporates sensory inputs from touch, proprioceptors (from muscles, tendons, and joints) and vision that originate from our various body parts, each with different sensory, motor, emotional, and social functions (Caggiano, 2020; Lackner & DiZio, 2000). All of these inputs are handled and integrated by several different areas in the brain - including the premotor, temporoparietal, posterior parietal, and extrastriate cortices (Blanke, 2012; Riva, 2018). Complex representations of the body as an entity and of the body as it exists in space may then be constructed or refined using these signals (e.g., Longo et al., 2010). Multiple sensory inputs

provide direct and indirect cues about body size and shape that allow the brain to build up an internal body representation in the course of development. Body representation has been found to be dynamic and flexible (Ferrè & Haggard, 2016; Longo et al., 2008; Whiteley et al., 2008), with a strong susceptibility towards changing brought on by multisensory illusions often involving manipulation of proprioceptive information (e.g., Bruno & Bertamini, 2010) which can alter body representation temporarily. However, it is still not fully understood how we perceive the structure of our bodies or how the body is represented in the brain.

1.1. The Representation of the Body in the Brain

How we perceive our bodies and how the body is represented in the brain is not yet fully understood despite over a hundred years of investigation since Head and Holmes' pioneering work (Head & Holmes, 1911). Head and Holmes based their work on neurological patients who had suffered damage in the parietal region of their brains (Head & Holmes, 1911). These patients could not identify where they had been touched, showing the importance that body representation has on the ability to localize tactile stimuli. A quote from their classic 1911 paper that indicates that body representation is far removed from the signals in the somatosensory cortex is "Anything which participates in the conscious movement of our bodies is added to the model of ourselves and becomes part of these schemata: a woman's power of localization may extend to the feather in her hat" (Head & Holmes, 1911).

We need accurate information about our bodies in order to interpret and react to sensory information that is constantly being received and that is coded relative to our body and yet how well we know the dimensions of our body and the stability of this representation is currently unknown. At the most basic level, body representation arises from unisensory inputs originating

from different body parts, with different sensory, motor, emotional, and social functions. Complex representations of the body and of the body in space may then be constructed from somatosensory, proprioceptive, and visual signals (Longo et al., 2010). Many studies have shown how inaccurate we are at judging our body size using both perceptual and behavioural methods (Keizer et al., 2013; Linkenauger et al., 2013, 2017; Longo, 2016; Longo, 2019; Mazzurega et al., 2018; Sadibolova et al., 2019; Stefanucci & Geuss, 2012; Wignall et al., 2017). Recent studies, including my own (D'Amour et al., 2015; Harris et al., 2015), have shown that our body representation can be altered (Brooks et al., 2020; Cardinali et al., 2012; de Vignemont et al., 2005; Kilteni et al., 2015; Lackner, 1988; Liu & Medina, 2017; Preuss & Ehrsson, 2019; Radziun & Ehrsson, 2018; Tsakiris et al., 2010; Tsay et al., 2015) both instantaneously and in the longer term.

1.2. Classifications of Body Representation

There are two main ways of talking about body representation (de Vignemont, 2010; Dijkerman & de Haan, 2007; Gallagher, 2005; Head & Holmes, 1911) – the body schema and the body image. Although they are related these terms refer to quite different things.

The body schema consists of sensorimotor representations of the body that guide actions. It is a dynamic representation and is updated constantly to include the relative positions of body parts derived from multiple sensory and motor inputs that interact with motor systems in the genesis of actions (Schwoebel et al., 2002). The body schema provides information about the body necessary to move such as initial posture, and limb size and potential strength (Schwoebel & Coslett, 2005). The body schema is largely unconscious and is necessary for, for example, localizing touches on a particular area and knowing where that location is in space as well as

relative to the body surface. The body schema is built up during development (Riva, 2018) and probably requires integrating of visual and proprioceptive information with some innate initial representation.

Emerging from this representation is the conscious multifaceted representation, known as the body image. Body image is made up from perceptual, affective, behavioural, and cognitive components, which allows us to form a mental picture our own body (Pitron et al., 2018; Riva, 2018; Slade & Brodie, 1994). The body image is an abstract, semantic, time-stable representation, which is retrieved explicitly and consciously (de Vignemont et al., 2005; Lackner, 1988). It can also be the idea of what our body looks like when viewed by someone else and is largely developed from seeing ourselves indirectly in a mirror. The concept of body image has been a topic of lively debate in literatures between cognitive neuroscience and clinical eating disorders areas, even though these literatures have made relatively little contact (Behrens et al., 2020; Caggiano, 2020; Fuentes, Longo, et al., 2013; Ganea & Longo, 2017; Gardner & Brown, 2010c; Heinberg, 2001; Legenbauer et al., 2020; Longo & Haggard, 2012b; Maresca et al., 2020; Mölbert et al., 2017; Nazareth et al., 2020; Sturman et al., 2017). Cognitive neuroscience approaches body image from the perspective that the body is represented in the brain and aims to understand how the multiple neural and mental representations of the body interact between the self and the external world (Berlucchi & Aglioti, 2010; Caggiano, 2020; Cardinali et al., 2012; Fontan et al., 2017; Fuller-Tyszkiewicz et al., 2020; Longo et al., 2010). Clinical research on eating disorders focuses on the body image as it might apply to diagnosis criteria and for treatments, in order to investigate what causes body image disturbances observed in anorexic and bulimic patients (Ben-tovim et al., 1990; Cash & Deagle, 1997; Ferrer-García & Gutiérrez-

Maldonado, 2012; Griffen et al., 2018; Mohr et al., 2016; Schneider et al., 2009; Smeets et al., 2009; Thompson, 2004).

1.3. Body Schema vs Body Image

While it is generally agreed that there are these two distinct types of body representation – body schema and body image - there is still little agreement beyond that (de Vignemont, 2010; Gadsby, 2018; Gallagher, 2005; Gallagher, 1986; Pitron et al., 2018). One school considers that the body image includes all representations of the body that are not used implicitly for action, whether perceptual, conceptual or emotional (Dijkerman & de Haan, 2007; Gallagher, 1986; Paillard, 1999). The second school retains the notion of body schema but rejects the notion of body image entirely because of its inconsistency. Instead, in this way of thinking, body image is split into two distinct body representations – 1) the body structural description and 2) the body semantics (Schwoebel & Coslett, 2005; Sirigu et al., 1991).

1.3.1. Body Structural Description

The body structural description is a long-term representation of the spatial organization of the body parts that contains representations about 1) the shape and contours of the human body, 2) a detailed plan of the body surface, and 3) the location of body-parts, the boundaries between them and their internal part-relation (Kammers et al., 2009; Longo & Haggard, 2010; Rusconi et al., 2009; Schwoebel & Coslett, 2005). The body structural description is based on vision and somatosensory perception.

1.3.2. Body Semantics

At the semantic level, the body image is primarily conceptual and linguistic and is defined in terms that describe the functional purpose of body parts and the categorical relationship between them (e.g., wrist and ankles are both joints). There are four main components of semantic knowledge about bodies - 1) knowledge about typical shape of body parts, 2) knowledge of the spatial location of a body part within the body as a whole, 3) knowledge of the characteristic functions of body parts, and 4) knowledge of the cultural associations such as clothing, jewellery, hygienic devices, etc., and how they relate to body parts (Kemmerer & Tranel, 2008).

1.4. Distinction between Representations

Even with these dissociations between the types of body representations, there are still issues due to the fact that elements of these representations have varying levels of relevance to different researchers. There are three main criteria used to draw the distinction between the different types of body representation. First is the availability to consciousness, which separates body representation into unconscious vs. conscious; second is dynamics of short-term vs. long-term, and last is the functional role of whether body representations are used for action vs. perception (Caggiano, 2020; de Vignemont, 2010b; Gadsby, 2017; Pitron et al., 2018). The weight of these criteria varies with the author. For example, Head & Holmes (1911) favour availability and dynamics whereas other authors might combine availability and functional role. Some just exclusively highlight the importance of one aspect. This can result in having the same notion being applied to opposite properties by different authors. As progress has been made in

the field, there has also been a shift towards the consideration that body schema and body image might not be so distinct from each other as once was thought. The move to viewing these two concepts as an interaction that can potentially build, form, and reshape each other can allow for a more coherent, generalized version of body representations.

1.5. Body Size Perception

Body size and shape perception have traditionally been investigated by exploring the conscious body image (a cognitive, subjective, mental body representation), most often in those with eating disorders (Alexi, Palermo, et al., 2019; Engel & Keizer, 2017; Gardner & Brown, 2014a; Gaudio et al., 2014; Hagman et al., 2015; Mölbert et al., 2017; Molinari, 1995a; Mussap et al., 2008a; Probst et al., 1995; Riva & Dakanalis, 2018; Schneider et al., 2009; Serino et al., 2018; Vocks et al., 2007). Both perceptual and behavioral techniques have assessed body perception by using tasks that involve comparing a participant's body with either pictures of their own body (depictive measures) or of objects (metric measures). These studies have revealed that people are inaccurate at judging their body size, suggesting that body perception distortions are found in both clinical and normal populations (Behrens et al., 2020; Brodie et al., 1989; Farrell et al., 2005; Fuentes, Pazzaglia, et al., 2013; Gardner & Boice, 2004; Gardner & Brown, 2010a, 2010b; Linkenauger et al., 2015; Longo, 2016; Peterson et al., 2003; Probst et al., 1995; Sadibolova et al., 2019; Thompson, 1996; Urdapilleta et al., 2010a).

However, these studies have generally lacked rigorous experimental methods and the results have been mixed and inconsistent, depending on the factors that were used such as: experimental stimuli, methods, location, situation, concept definitions, etc. (Alexi, Dommissie, et

al., 2019; Bruch, 1962; Ekroll et al., 2016; Keeton et al., 1990; Moussally et al., 2017; Nelson & Gidycz, 1993; Probst et al., 1995; Shafran & Fairburn, 2002; Smeets et al., 1997; Stephen et al., 2019; Tamè et al., 2017; Vitousek & Manke, 1994). Studies that require picking a template or adjusting something to match perceived size, involve the conscious body image. Such tasks require a subjective perspective that involves personal opinions and feelings that someone may have about their body size. This requires reflecting on their conscious beliefs about their size but doesn't address the representation in the brain.

1.6. Purpose

My doctoral research aims to understand how we perceive and represent our bodies by investigating accuracy and stability of body size perception at the level of the representation in the brain (see Figure 1.1). My research is centered on two main themes - 1) Measuring Perceived Body Size and 2) Assessing the Plasticity of the Body Representation. The first part of my research looks at how accurate we are at detecting our actual body size compared to distorted images. The second investigates whether body size detection accuracy can be altered and if so, to what extent and for how long.

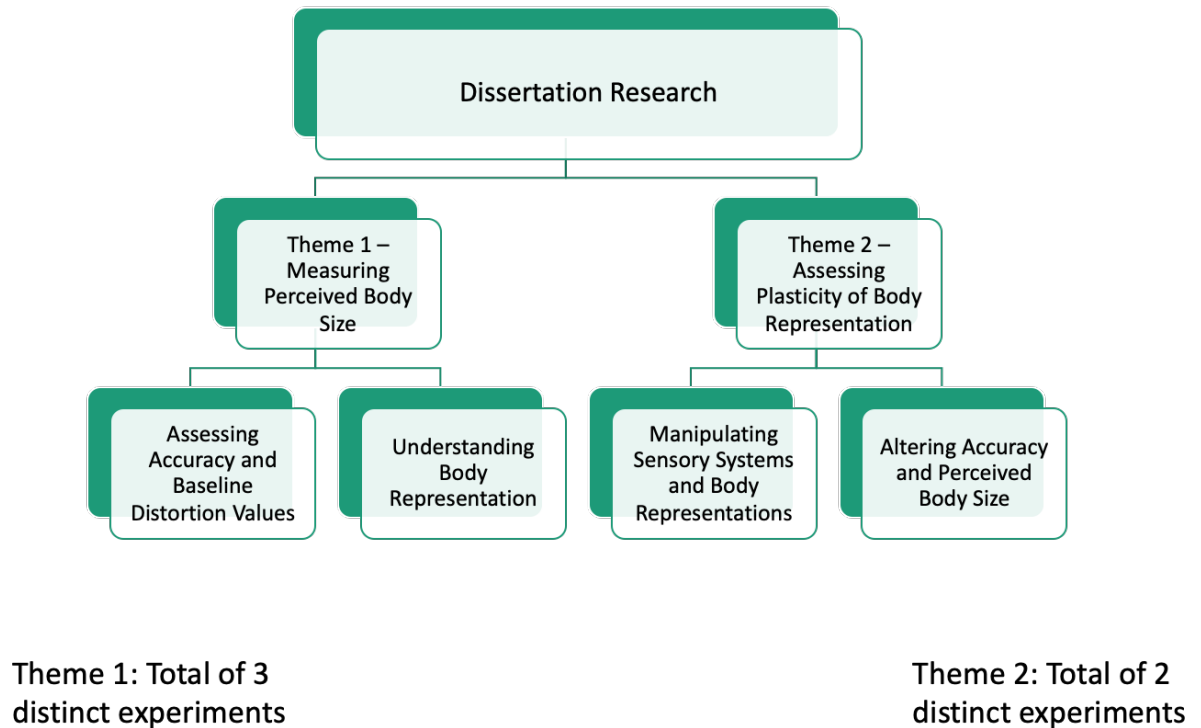


Figure 1.1. Schematic of my dissertation research.

1.7. General Experimental Method: Psychophysical 2AFC Adaptive Staircase Technique

In order to obtain an implicit measure of body size that taps into the body representation in the brain rather than an explicit measure that includes conscious and emotional aspects of body image, I developed a novel psychophysical method to obtain a quantitative, objective measure of how people perceive their body shape and size (see Figures 1.2 and 1.3). The implicit representation corresponds most closely to the representation in the brain and is not vulnerable to such emotional or cognitive influences. By using a two-alternative forced choice (2AFC) adaptive staircase method, I reduced response bias and the subjective nature of size judgments because participants do not have to use a subjective opinion (Green & Swets, 1966; Macmillan & Creelman, 2005). Participants had to choose which of two life-size photographs (an accurate

reference photograph or a photograph that had been distorted in the horizontal or vertical dimension) was most like them. The distorted image is then adjusted according to their decision. The end point is when the two images are judged as equally like them without either photograph necessarily matching their internal representation. Thus, they are never actually shown the image that corresponds to their internal representation of themselves. The subjective element (in which a participant might choose, for example, a photograph that was most like how they would like to look) is thus removed by my method as there was no a priori reason to choose either photograph. These judgments provide an estimate of difference from accurate of the representations in the brain that can be used for creating models and maps of how the brain perceives body size, shape, structure, etc. as previously investigated by for example, Fuentes, Longo, et al., (2013), Fuentes, Pazzaglia, et al., (2013), Linkenauger et al., (2009, 2015), Longo (2015d, 2016), Longo et al., (2015), Longo & Haggard, (2010, 2012b), Mancini, Longo, Iannetti, et al., (2011), and Pazzaglia & Zantedeschi, (2016).

Precision is the variation in a participant's judgments which can be obtained from the inverse of the standard deviation of the distribution of their decisions. Precision was not needed for testing most of the hypotheses examined in this dissertation. The QUEST adaptive staircase method is not the most efficient way of obtaining reliable estimates of the precision of participants' judgments but precision can be obtained by fitting a sigmoid function to all the data obtained from a given condition. This technique was used in Chapter 5 to test precision-related hypotheses considered in that chapter.

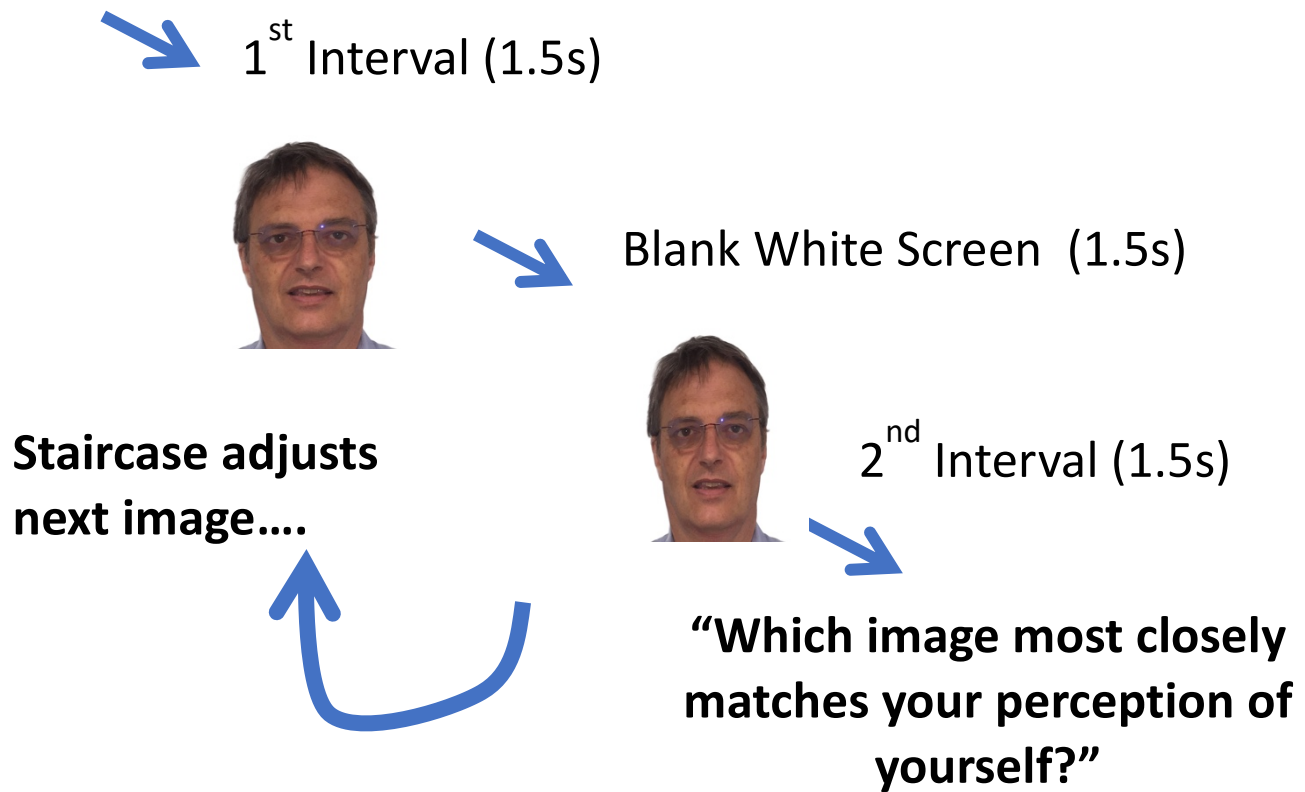


Figure 1.2. Schematic of a trial in the 2AFC perceived size accuracy task. Participants are shown two images successively and asked to choose which one most closely matched their perception of themselves.

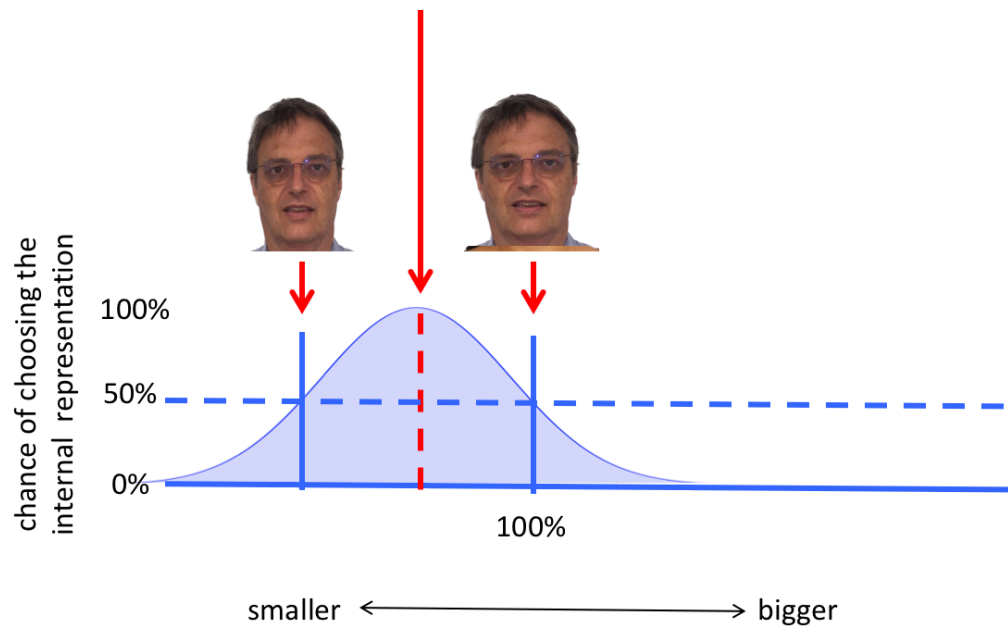


Figure 1.3. Measuring perceived size. The method finds the point at which the two images are equally likely to be selected (shown here diagrammatically by the two faces) from which their internal representation can be deduced. Perceived size is the point halfway between the actual size and the distorted value, both of which are judged as equally like the participant.

1.8. Theme 1: Measuring Perceived Body Size - Assessing Accuracy of the Perception of Body Parts

Perceived body size was examined using my psychophysical technique to determine how accurate people are at judging their body size. Width and length dimensions were distorted separately. The image was also presented in different orientations (such as upright, right, left, and upside down) in order to assess how accuracy perception changes when the image is presented in familiar and unfamiliar views. I conducted three separate, distinct experiments to test the representation of the face (Chapter 2), the hand and palm (Chapter 3), and the full body

(Chapter 4). The main goal of these studies was to measure accuracy in different orientations, for both the width and length dimensions, to obtain baseline values of how distorted the brain's representation of various body parts are and how well it can be accessed and mentally rotated to be compared to body parts presented in these different orientations. My hypothesis was that there would be significant distortions from accurate, showing that perceived size distortions exist even in healthy populations. My second hypothesis was that there would be differences between the orientations in which the body parts are viewed, with greater distortions expected for unfamiliar orientations (e.g., upside down).

Two additional factors were also assessed – 1) Sex and 2) Body satisfaction – measured using The Body Shape Questionnaire (BSQ) (Cooper et al., 1987). Previous literature has tended to concentrate on females (Alexi et al., 2018; Cornelissen et al., 2017; Docteur et al., 2012; Gleghorn et al., 1987; Gould-Fensom et al., 2019; Molinari, 1995; Slade & Russell, 1973; Thompson & Spana, 1988); but see (Cafri & Thompson, 2004; Cordes et al., 2016; Dolan et al., 1987; Galioto & Crowther, 2013; Mazzurega et al., 2018; Urdapilleta et al., 2010) which do include males). This bias has created a lack of knowledge about how males represent their bodies and whether they might also show distortions in size perception. Both males and females were tested in my experiments in order to see if sex differences exist by examining whether they actually do occur or not and to add to the current literature. Previous literature has also suggested that body distortions occur more in those dissatisfied with their bodies (Cash & Deagle, 1997; Hrabosky et al., 2009; Mai et al., 2015; Mohr et al., 2011; Sand et al., 2011; Stice & Shaw, 2002) but these studies have also widely focused on clinical eating disordered populations with high levels of body dissatisfaction and have often overlooked the healthy population (but see (Bould et al., 2020; Fuller-Tyszkiewicz et al., 2019; Galioto & Crowther, 2013; Gunnare et al., 2013;

Preston & Ehrsson, 2014, 2014, 2018). BSQ scores were analyzed and low and high BSQ groups were compared to determine if there are relationships and correlations between body size accuracy and body satisfaction. My third and fourth hypotheses are that there would be differences related to both sex and body satisfaction, with females and those with higher levels of body dissatisfaction showing greater distortions.

1.9. Theme 2: Plasticity of the Body Representation - Altering Accuracy by Manipulating Perceived Body Size

Visual, proprioceptive, tactile, and vestibular information are integrated to provide direct and indirect cues about body size and shape (Serino & Haggard, 2010). The brain maintains an internal body representation but is also required to plastically adjust and update this representation in response to changes in body shape during growth and development (Gallace & Spence, 2010). The consequences of altered body representation on sensory perception have frequently been used as an indirect way of examining the nature and extent of this plasticity (e.g., Serino & Haggard, 2010).

Artificially altering body representation may have serious consequences on many aspects of perception. Surprisingly, the ability to change many aspects of body perception (such as body size accuracy and stability) are unknown. To explore the nature and extent of the brain's plasticity and flexibility, I investigated how manipulating body representation affects body perception and whether accuracy values can be changed. Body perception was distorted, disrupted, and modulated using two separate methods that alter the vestibular (Chapter 5) and visual (Chapter 6) sensory information.

1.9.1. Manipulation 1: Vestibular Stimulation

Vestibular signals are fundamental for achieving a coherent representation of the body due to the strong link that the information provides for sense of self and awareness of one's own body (Ferrè & Haggard, 2016; Lopez, Schreyer, et al., 2012). Disruptive galvanic vestibular stimulation was used to disrupt the stabilizing of the body schema to see if the ability to perceive own body size is affected. My hypothesis was that disruptive galvanic vestibular stimulation (dGVS) would result in changes to perceived body size accuracy and precision.

1.9.2. Manipulation 2: Visual stimulation

Visual adaptation was used to see if exposure to distorted visual feedback can alter perceived body size accuracy and for how long. My hypothesis was that altering visual feedback will cause changes in perceived body size, with accuracy values following the direction of adaptation. I expected that adapting to a bigger body would result in size overestimations whereas underestimations would occur when adapted to a smaller body. Several accuracy measurements were taken to assess the time course for any adaptation effects. My second hypothesis for this theme was that visual adaptation, even with a brief period of exposure, would impact accuracy and stability of body representation. These changes would then alter over time, with decay occurring in each of several sequential test session. My third hypothesis was that there would be differences between the adaptation directions. I predicted that adapting to a bigger body would show more effectiveness and have greater changes in accuracy.

CHAPTER 2:

Perceived Face Size in Healthy Adults

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2.1. Abstract

Perceptual body size distortions have traditionally been studied using subjective, qualitative measures that assess only one type of body representation – the conscious body image. Previous research on perceived body size has typically focused on measuring distortions of the entire body and has tended to overlook the face. Here, we present a novel psychophysical method for determining perceived body size that taps into implicit body representation. Using a two-alternative forced choice (2AFC), participants were sequentially shown two life-size images of their own face, viewed upright, upside down, or tilted 90°. In one interval, the width or length dimension was varied, while the other interval contained an undistorted image. Participants reported which image most closely matched their own face. An adaptive staircase adjusted the distorted image to hone in on the image that was equally likely to be judged as matching their perceived face as the accurate image. When viewed upright or upside down, face width was overestimated and length underestimated, whereas perception was accurate for the on-side views. These results provide the first psychophysically robust measurements of how accurately healthy participants perceive the size of their face, revealing distortions of the implicit body representation independent of the conscious body image.

Keywords: Body representation, face perception, perceptual size distortion, face orientation, sex differences

2.2. Introduction

It is crucial that our brain accurately represents our bodies in almost all situations, especially those involving perception and action. Yet, it is still not fully understood how we perceive the structure of our bodies or how the body is represented in the brain. Perceived body size is a fundamental construct that reflects our knowledge of self and is fundamental to all aspects of perception. It relies on mental body representation maps that have been assumed to be accurate in healthy adults. The motivation for the present study was to examine face size perception in healthy populations of males and females using a robust psychophysical method in order to measure implicit body representation rather than body image. While perceived face size may be correlated with body mass index (BMI) (Coetzee et al., 2009), here we reveal errors in people's perception of their own face, showing that the assumption of an accurate body representation in healthy adults is not correct.

Research on body size perception has typically focused on the whole body or particular body parts that are assumed would have distortions, such as the stomach, thighs, or upper arms – areas of the body that tend to be higher in fat content (Farrell et al., 2005; Keizer et al., 2014; Smeets et al., 1997). However, since these studies were aimed at understanding distortions that occur in clinical populations, such as those with eating disorders, they have tended to ignore the face (but see (Linkenauger et al., 2015)). Unlike many parts of the body, the face has some special attributes that make it unique - it has internal features, and it cannot be viewed directly: only in mirrors. Thus, visually guided interactions with the face (such as shaving or putting on makeup) are fundamentally different from how we interact with our hands, arms, legs, etc. Face perception, including the ability to recognize and represent properties of the face, is a critical

aspect of self-awareness that requires an accurate representation (Apps et al., 2015; Cardini et al., 2011; Frassinetti et al., 2008; Keyes et al., 2010; Leopold & Rhodes, 2010). But how accurate is this representation? Previous research has shown that body image distortions occur in healthy people. Participants tend to overestimate the width of their shoulder and the length of their upper arms, while underestimating the lengths of their lower arms and legs. Interestingly, distortions were similar for both males and females (Fuentes, Longo, et al., 2013). Are such misrepresentations of the body reflected in the perceived size of the face?

Body size and shape perception have traditionally been investigated by exploring the conscious body image (a cognitive, subjective, mental body representation), most often in those with eating disorders (Gardner & Brown, 2014; Molinari, 1995; Probst et al., 1995). Both perceptual and behavioral techniques have assessed body perception by using tasks that involve comparing one's own body with either pictures of the body (depictive) or objects (metric) measures. These studies have revealed that people are inaccurate at judging their body size, suggesting that body perception distortions are found in both clinical and normal populations (Brodie et al., 1989; Farrell et al., 2005; Fuentes, Pazzaglia, et al., 2013; Gardner & Boice, 2004; Gardner & Brown, 2010a, 2010b; Peterson et al., 2003; Probst et al., 1995; Thompson, 1996; Urdapilleta et al., 2010). However, these studies have generally lacked rigorous experimental methods and the results have been mixed and inconsistent, depending on the factors that were used such as: experimental stimuli, methods, location, situation, concept definitions, etc. (Bruch, 1962; Keeton et al., 1990; Nelson & Gidycz, 1993; Probst et al., 1995; Smeets et al., 1997; Vitousek & Manke, 1994). Studies that require picking a template or adjusting to match perceived size involve the conscious body image. Such tasks require a subjective perspective that involves personal opinions and feelings that someone may have about their body size. This

requires reflecting on their conscious beliefs about their size but doesn't address the representation in the brain. Recent studies have explored body perception in normal populations using psychophysical techniques and have found that distortions exist even in healthy adults (Brooks et al., 2016; Stephen et al., 2016; Sturman et al., 2017). By using a two-alternative forced choice task (2AFC), we reduced response bias and the subjective nature of size judgements because participants no longer had to use a subjective opinion (Green & Swets, 1966; Macmillan & Creelman, 2005). In our experiments participants had to choose which of the two photographs (an accurate reference photo or a photo that had been distorted in the horizontal or vertical dimension) was most like them. The end point was when the two images were judged as equally like them without either photograph necessarily matching their internal representation. The subjective element (in which a participant might choose, for example, a photograph that was most like how they would LIKE to look) was thus removed by our method by avoiding responses biased by personal feelings (there was no a priori reason to choose either photograph). This provided an implicit measure that taps into the brain's body representation rather than an explicit measure that includes conscious and emotional aspects of body image. The implicit representation corresponds most closely to the representation in the brain and is not vulnerable to such emotional or cognitive influences. These judgments thus provide a window into the representations in the brain that can be used for creating models and maps of how the brain perceives body size, shape, structure, etc. (Fuentes, Pazzaglia, et al., 2013; Fuentes, Longo, et al., 2013; Linkenauger et al., 2009, 2015; Longo, 2015a; Longo, Mancini, et al., 2015; Longo, 2016; Longo & Haggard, 2010, 2012b; Mancini, Longo, Kammers, et al., 2011; Pazzaglia & Zantedeschi, 2016).

Here, we applied this technique to measure the perception of the face in a healthy population to determine how the face might be represented in the brain. We measured width and length accuracy in four different face orientations to obtain baseline values of the distortion in the brain's representation and to gain knowledge about the flexibility of the representation. We expected to find significant perceptual distortions, showing that distortions exist even in healthy populations. While we frequently see our face in the mirror, we don't interact with it or see it in the same way that we do with the rest of our bodies. While we can see our hands directly in multiple different viewpoints, we only obtain visual information about our face from mirrors or photographs. This may lead to distortions of our body representations as the brain pieces together perceived size and shape from essentially a single perspective. We also predicted that there would be differences depending on the orientation in which the face was seen, with more pronounced errors when viewing the face in unfamiliar views. Previous literature has tended to test almost only female participants (Gleghorn et al., 1987; Molinari, 1995; Slade & Russell, 1973; Thompson & Spana, 1988) and has shown that body distortions occur more in those dissatisfied with their bodies (Cash & Deagle, 1997; Hrabosky et al., 2009; Mai et al., 2015; Mohr et al., 2011; Sand et al., 2011; Stice & Shaw, 2002). Here, we compared low and high body dissatisfaction groups in both male and female participants in order to add to the literature and advance knowledge about how sex and body satisfaction contribute to size perception. Based on the literature we expected that females and those with higher levels of body dissatisfaction would show greater perceptual distortions. We did not know how accurately males might perceive their face size.

2.3. Methods

2.3.1. Participants

Forty participants took part in the experiment (20 females, mean age 23.1 years, SD = 9.0 years). They were recruited from the York University Undergraduate Research Participant Pool and received course credit for taking part in the study. The experiment was approved by the York Ethics Board and all participants signed informed consent forms. The individual whose face is shown in Figure 2.1 in this manuscript has given written informed consent (as outlined in PLOS consent form) to publish these case details. The study was performed in accordance with the Treaty of Helsinki. The sample size was based on previous work to determine the power needed for significance and the potential variability within and between groups. Size for each sex group was kept equal, with an amount that would be sufficient to detect differences.

2.3.2. Materials and Stimuli

Body dissatisfaction

The Body Shape Questionnaire (BSQ) (Cooper et al., 1987), a 34-item self-report questionnaire that was developed to assess concerns about body shape and experiences of feeling fat within the previous month, was administered before the experiment began to obtain a measure of body dissatisfaction. Higher scores indicate higher levels of body dissatisfaction. Participants were divided into high and low groups defined as whether their score was above or below the overall mean score.

Photographs

Color photographs of each participant were taken using an iPhone 6 camera (focal length = 4.15mm, sensor size = 4.8 x 3.6mm; 73° field of view). Participants were asked to stand in front of a wall with a neutral facial expression. Photographs were taken under standardized conditions with the flash on, from just above the head to the waist, from a distance of approximately four feet with no zoom function. The image was then cropped and flipped to include only the participant's head in mirror perspective, and formatted with a white background (Adobe Photoshop CS6) (magnification 180x relative to the sensor size). This image served as the undistorted "real" image and was used for composing the distorted images. Using a soft tape measure, face size was measured straight down from the top of the forehead to the bottom of the chin. The image was then adjusted to match the participant's actual face size.

Distorting the images

Images were presented and distorted through the use of MATLAB (version 2011b) and Psychophysics Toolbox (Brainard, 1997) running on a MacBook Pro. One dimension of the image (either width or length) was distorted (made either bigger or smaller) using a QUEST adaptive staircase psychometric procedure (Watson & Pelli, 1983). Optical distortions of the lens were confirmed as being less than 0.3% of the width or length of the photograph (given that the other length was set to veridical) using Matlab to assess the amount of distortion. The monitor was viewed orthogonally to the line of sight with the viewer aligned with in the center of the photograph. The image was displayed on the center of a computer monitor (27-inch Apple display) with the face in one of the four orientations shown in Figure 2.1: (1) upright (0°), (2) to the right (90°), (3) upside down (180°), and (4) to the left (270°). Width and length dimensions

were distorted separately for each of the four orientations, in a block design resulting in eight conditions.

2.3.3. Procedure

Participants sat in a chair approximately 45 cm in front of the computer screen. Each trial consisted of two 1.5s intervals – one interval containing the undistorted image and one interval containing the distorted image - separated by a blank white screen. Participants identified which interval contained the image that most closely matched their own perception of their face and responded using a two-button computer mouse (left button for first interval, right button for second interval). A QUEST adaptive staircase procedure (Watson & Pelli, 1983) was used with a two-alternative forced choice (2AFC) design to vary the chosen dimension (length or width) of the distorted image. Two QUEST staircases (25 trials per staircase) were used for each condition (50 trials total), with one starting with the manipulated dimension larger than natural and the other starting with that dimension smaller than natural. Each of the eight conditions was run in a single block and took approximately six minutes to complete. Block order was determined by a Latin square and was counterbalanced across participants.

It has been reported that viewing a photograph from a distance different from the camera's focal length multiplied by the magnification (75cm in this case) can produce subtle perceptual effects (Cooper et al., 2012). We confirmed that viewing distance had no effect on our data by repeating our experiment on a selection of participants viewing the same photographs at a range of distances from 25-240cm.

2.3.4. Data Analysis

The QUEST program returned an estimate of the distortion needed for the participant to report that the distorted image was equally like their perceived face size as the undistorted image. The algorithm assumes the observer's psychometric function follows a Weibull distribution and adaptively determines the amount of distortion to be presented based on the participant's response to the previous trials. As the experiment goes on, knowledge on the observer's psychometric accumulates. To visualize and confirm the QUESTs performance, the participant's decision was plotted against the distortion used for each trial and fitted with a logistic (Equation 2.1) using the curve fitting toolbox in MATLAB.

$$\text{Decision} = 1/(1+\exp(-(x-x_0)/b)) \dots\dots\dots (2.1).$$

where x_0 is the actual size, x is the distorted value that was equally likely to be judged as matching the observer's face size and b is an estimate of the slope of the function. The perceived size of the face was taken as the point half way between x and x_0 .

All of the 40 participants' data for each condition was examined to validate the accuracy and efficiency of the QUEST procedure. The QUESTs performance was also checked to determine whether reliable estimates were obtained within 50 trials. All data were inspected for outliers. Outliers were assessed as points that fell outside ± 3 standard deviations from the mean. Data that failed to meet these criteria were discarded from the analyses (one participant).

Estimates were converted to percentages relative to the accurate reference photograph ($x*100/ x_0$) and data analyses were conducted on these values. One-sample t tests were

conducted for each condition to assess whether accuracy errors differed significantly from zero (p values corrected for multiple comparisons with the false discovery rate method (Benjamini & Hochberg, 1995), $\alpha = .008$). Mixed measures analyses of variances (ANOVAs) were used for statistical analyses, with α set at $p < .05$ and post-hoc multiple comparisons were made using Bonferroni corrections.

2.4. Results

Table 2.1 summarizes the results of t -tests showing that the perceived width and length of upright and upside down faces were significantly different from accurate.

Table 2.1

One-Sample t -Tests Comparing Mean Accuracy Errors to 0.

		<i>M (SEM)</i>	<i>t</i> (38)	<i>p</i>	95% CI
Width	Upright	1.51(.53)**	2.87	.007	[.44, 2.57]
	Right	-0.64(.60)	-1.07	.290	[-1.85, .57]
	Upside Down	2.59(.80)**	3.24	.002	[.97, 4.20]
	Left	0.13(.92)	0.14	.890	[-1.73, 1.98]
Length	Upright	-1.28(.51)*	-2.50	.017	[-2.32, -.24]
	Right	-0.97(.71)	-1.38	.176	[-2.40, .46]
	Upside Down	-1.97(.59)*	-3.34	.002	[-3.16, -.77]
	Left	0.14(.60)	0.24	.814	[-1.07, 1.35]

Note. $N = 39$. CI = confidence interval.

* $p < .025$. ** $p < .0125$.

2.4.1. Perceived Face Width

Figure 2.1 (upper graph) plots the deviation from accurate of width judgements for faces in each orientation tested (shown below the graph) with the participants divided into five categories: overall, males, females, low BSQ and high BSQ scorers. A three-way mixed ANOVA was conducted to test for within-subjects effects of orientation (upright, right, upside down, and left) and between-subjects effects of sex (male and female) and BSQ score (low and high groups). A significant main effect of orientation, $F(3, 105) = 4.44, p = .006, \eta_p^2 = .113$, was revealed, which implies that there are differences in perceiving face size depending on the orientation in which the image was viewed. Pairwise comparisons showed significant differences between the upright ($MD = 2.26, SE = .61, p = .004$) and upside down ($MD = 3.16, SE = .86, p = .004$) orientations compared to the right orientation. Participants overestimated face width by $1.44\% \pm .54$ when the image was viewed upright and by $2.33\% \pm .76$ when the face was upside down compared to being underestimated by $0.83\% \pm .64$ in the right-side-down orientation. No significant interactions were found between orientation and sex, $F(3, 105) = .92, p = .435, \eta_p^2 = .026$, orientation and BSQ group, $F(3, 105) = 1.06, p = .372, \eta_p^2 = .029$, or between orientation, sex, and BSQ group, $F(3, 105) = .82, p = .487, \eta_p^2 = .023$.

There was a between-groups effect for sex, $F(1, 35) = 5.67, p = .023, \eta_p^2 = .139$, which indicates that males and female differ in perceived face width accuracy, but not for BSQ group, $F(1, 35) = .39, p = .534, \eta_p^2 = .011$. Females overestimated face width by $2.06\% \pm .73$ whereas males underestimated by $0.39\% \pm .73$ ($MD = 2.46, SE = 1.03, p = .023$). No significant interaction between sex and BSQ group, $F(1, 35) = .01, p = .924, \eta_p^2 = .00$, was found. To break

down the effect of sex on orientation, a one-way ANOVA was conducted. Significant differences between males and females were only found for the upright, $F(1, 37) = 7.89, p = .008$, and upside down, $F(1, 37) = 11.01, p = .002$, orientations.

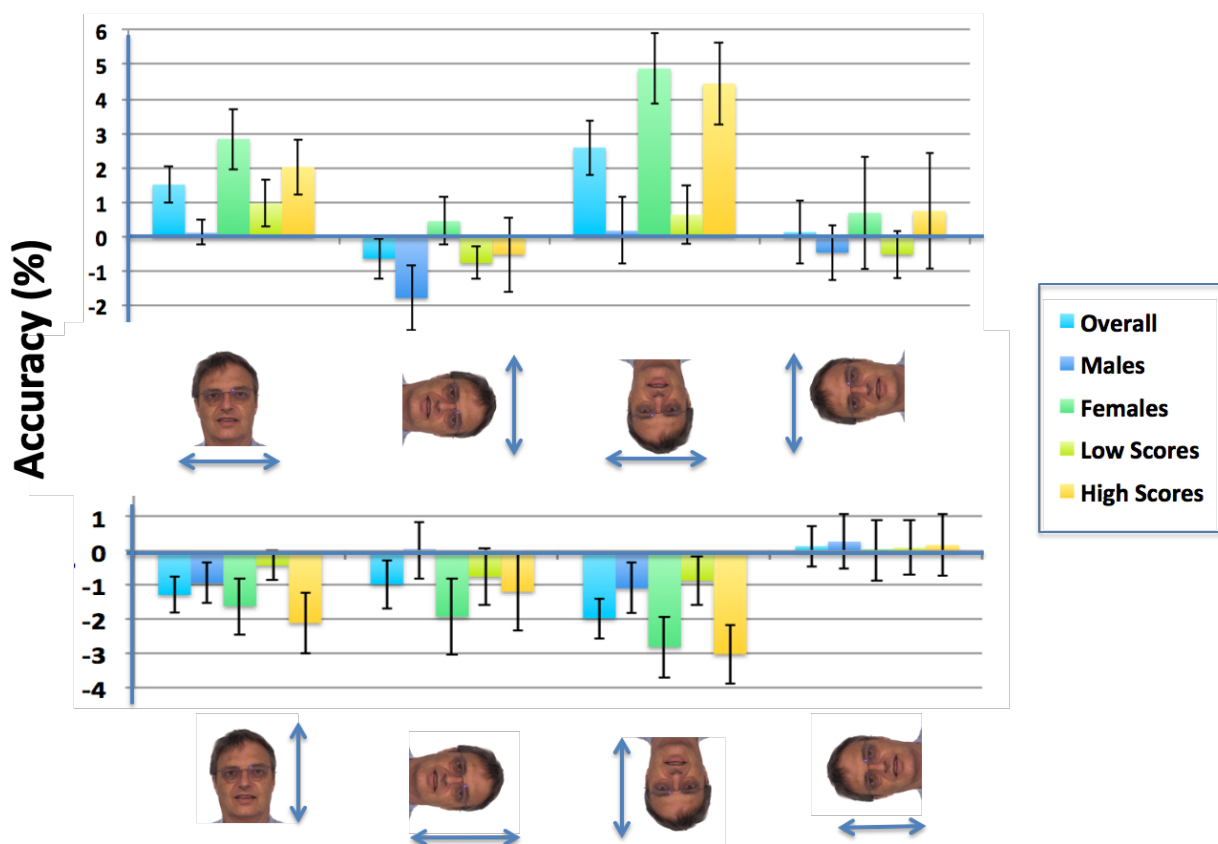


Figure 2.1. Deviation from accurate results when face width (top row) or face length (bottom row) was distorted for each viewing orientation. Average percentages are shown across all between-subjects groups. Positive and negative scores represent overestimation and underestimation respectively. Error bars represent ± 1 SEM. The individual in this manuscript has given written informed consent (as outlined in PLOS consent form) to publish these case details.

2.4.2. Perceived Face Length

Figure 2.1 (lower graph) plots the deviation from accurate of length judgements for faces in each orientation with participants divided into the same five categories. A three-way mixed ANOVA was conducted to test for within-subjects effects of orientation (upright, right, upside down, and left) and between-subjects effects of sex (male and female) and BSQ score (low and high groups). A significant main effect of orientation, $F(3, 105) = 2.83, p = .042, \eta_p^2 = .075$, was observed but no significant interactions were found between orientation and sex, $F(3, 105) = .70, p = .553, \eta_p^2 = .020$, orientation and BSQ group, $F(3, 105) = 1.16, p = .329, \eta_p^2 = .032$, or between orientation, sex, and BSQ group, $F(3, 105) = .89, p = .446, \eta_p^2 = .025$. Pairwise comparisons did not show any significant differences between the orientations.

There was no between-groups effect for sex, $F(1, 35) = .95, p = .336, \eta_p^2 = .027$, or for BSQ group, $F(1, 35) = .62, p = .436, \eta_p^2 = .017$. However, a significant interaction between sex and BSQ group, $F(1, 35) = 5.29, p = .028, \eta_p^2 = .131$, was found. To follow up on this interaction, simple effects tests were conducted. Face size accuracy errors significantly differed between males and females for the high BSQ group ($MD = 2.85, SE = 1.22, p = .026$) but not for the low scoring group ($MD = 1.15, SE = 1.24, p = .359$). Females in the high BSQ group underestimated the length of their face by $2.38\% \pm .67$ compared to those in the low group who overestimated by $.31\% \pm 1.02$ ($MD = 2.69, SE = 1.22, p = .035$) whereas males in the low and high groups did not differ.

2.5. Discussion

We have measured how accurately healthy participants perceive the size of their face in four different orientations. This is the first time that this has been done using psychophysically robust measurements. We have showed that neither healthy males nor healthy females are completely accurate at judging the length and width of their faces, and that accuracy changes depending on the orientation in which the face is viewed. Curiously, the largest errors were found in the most familiar orientations, whereas participants were accurate when the face was viewed in the unfamiliar sideways orientation.

2.5.1. Overall Accuracy

Our finding that people perceive their face as wider and shorter than it actually is, regardless of body dissatisfaction or sex, is a novel finding that brings the traditional belief – that perceived body distortions are unique to females who are dissatisfied with their bodies (Bruch, 1962; Cash & Deagle, 1997; Hrabosky et al., 2009; Keeton et al., 1990; Smeets et al., 1997) - into question. It has been assumed that healthy people must have accurate body representations and only very recently has research begun to challenge this assumption (Fuentes, Longo, et al., 2013; Linkenauger et al., 2015; Longo, 2015b, 2016; Longo & Haggard, 2010, 2011, 2012b; Saulton et al., 2015). While these studies have started to explore body size perception, only a few studies have looked specifically at the face or head. Perceived length of body parts relative to each other was measured, finding that head-length estimates were mixed but mostly overestimated (Linkenauger et al., 2015). This finding is not compatible with our results of underestimated face length. However, our findings are supported by several studies that found similar distortion in body representation. For example, Fuentes et al. (Fuentes, Runa, et al., 2013)

investigated facial feature representation and showed an overall bias towards a short and wide face representation, and comparable distortions have also been observed for the hands (Longo, Mancini, et al., 2015; Longo & Haggard, 2010, 2012a, 2012b; Mancini, Longo, Iannetti, et al., 2011) and overall body shape (Fuentes, Pazzaglia, et al., 2013).

2.5.2. Sex and Body Satisfaction Scores

Here, we show that healthy people of both sexes demonstrate distortions in perceived face size, with males and females differing only in the magnitude of their errors. While a link between body satisfaction and perceived body size distortions is known (Eshkevari et al., 2012; Gardner & Bokenkamp, 1996; McCabe et al., 2006; Mussap et al., 2008) previous research has typically focused on comparing healthy and eating disorder groups, which are known to have clinical levels of body dissatisfaction. From these earlier studies, it has been assumed that those with higher BSQ scores, even within the healthy range, would show greater amounts of distortion compared to those with lower scores. Surprisingly we found that BSQ scores had an effect only on perceived face length: females in the high BSQ group underestimated face length compared to those in the low group, whereas males did not. Finding no effect of BSQ group on perceived face width tells us that this perceptual distortion depends on more than sex and body dissatisfaction levels.

2.5.3. The Effect of Orientation

We expected that accuracy would worsen when the face was presented in unfamiliar views. That is, that participants would be most accurate when viewing their face in the upright orientation, less accurate in left and right orientations, and worst when the face was presented

upside down. Surprisingly, our results did not match this pattern. Instead, we found that perceptual distortions only occurred when the face was presented upright or upside down and that participants were accurate (scores not different from 0) when the face was viewed tilted to the left or right. It is not clear why this might be. One possibility is that there is something special about the face when it is in typical face form – upright or upside down are both in the regular face shape orientation – whereas when the face is tilted to the left or right, it is taken out of the typical form and becomes a distinctive shape that is never normally seen. Creating such a peculiar view might cause a person to feel that the face is no longer theirs and they come to perceive the image as an external neutral object unrelated to the self. Thompson and Wilson (2012) showed that an inverted face appeared thinner than an upright face and that the effect appeared to be driven by the internal features of the face. They removed the distortion by removing the internal features. It seems that placing the features in an unusual orientation (by turning the face sideways) has the same effect, restoring accurate face size perception in all males and females.

2.5.4. Conclusions

The main objective of this study was to assess accuracy of the perceived face dimensions to develop a method of assessing body representation. We have shown, for the first time, how the brain quantitatively perceives the size of the face by measuring baseline measurements of distortions with the face in several orientations. The implicit representation of the face in the brain, does not appear to be the same as the face seen in the mirror. These data reveal how accurately people are able to judge their body dimensions and provide insight into how body size and shape are processed and represented by the brain. Future research will use this method to

further examine the perception of body dimensions to quantify and compare how distortions vary under different experimental designs, such as testing the effects of image size, different body parts, and the whole body in order to develop a comprehensive understanding of the three-dimensional representation of the body in the brain.

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CHAPTER 3:

The Perceived Size of the Implicit Representation of the Dorsum and Palm of the Hand

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3.1. Abstract

The perception of the body and its parts has traditionally been studied using the conscious body image. Here, we determine the implicit representation of the hand. Participants were sequentially shown two life-size images of either the dorsal or palmar surface of their hand. In one interval either the horizontal or vertical dimension of the image was varied using an adaptive staircase, while the other interval contained the full-size, undistorted image. Participants reported which image most closely matched their hand. The staircase honed in on the distorted image that was equally likely to be judged as matching their own hand as the accurate image. The implicit representation was taken as midway between these two images. The experiment was repeated with different hand orientations. Perceived width depended on the orientation, with differences found between the upright and right orientations. Interestingly, the perceived length of the dorsum and palm were different from each other – length of the dorsum was overestimated whereas palm length was perceived accurately. This study reveals distortions of the implicit representation of the hands in healthy individuals.

Keywords: Body representation, perceived size, hand perception, palm perception, perceptual size distortion, body orientation

3.2. Introduction

The perception of our hand size is critical for our interactions with the world – especially for finer work. The relative lengths of our fingers and the proportions of our hands are part of defining ourselves. The hand is also our primary organ for exploring the world by touch. Although the palmar side of the hand (specifically the finger tips) is the part used for touching things (with its covering of glabrous skin and notorious concentration of tactile sensors), it is the relatively insensitive dorsum of the hand (covered largely with hairy skin) that is generally visible.

The hand has been the main focus for studying various aspects of perception and action such as touch, haptics, motor skills, reaching, grasping, pointing, tool use, position sense, size perception, etc. (Cardinali et al., 2009; Coelho et al., 2017, 2019; Coelho & Gonzalez, 2018; Longo, 2014; Longo, 2015c; Longo, Mancini, et al., 2015; Longo, Mattioni, et al., 2015; Longo, 2019; Longo & Haggard, 2010, 2011, 2012a, 2012b; Peviani & Bottini, 2018) and so it is important to get a complete picture of how the hand is represented in the brain. All these sensory processes and tasks require knowledge about how the brain represents the hand and therefore can be impacted by any size or shape distortions that may occur. We recently developed a novel psychophysical method for determining perceived body size that provides an objective, unbiased, implicit measure of the body representation in the brain (D'Amour & Harris, 2019; D'Amour & Harris, 2017). Here, we examine the perceived size of the dorsum and palm of the hand to determine and compare baseline size accuracy when the hand is viewed in various orientations and to compare the representation of the two sides of the hand.

Previous studies looking at how the hand is represented have used methods that involve making judgements based on the perceived location of landmarks, such as the knuckles and

fingertips (Ambroziak et al., 2018; Coelho et al., 2017; Coelho & Gonzalez, 2018, 2019; Longo, 2014; Longo, 2015c; Longo, Mancini, et al., 2015; Longo, Mattioni, et al., 2015; Longo & Haggard, 2010, 2011, 2012a, 2012b; Saulton et al., 2015, 2016). These judgments require participants to point to landmarks on their occluded hand, from which maps of perceived size are produced by comparing differences between judged and actual position. This type of task is effective at determining a body model that is based on position sense and postural information of the hand but is potentially complicated by inaccuracies in proprioception, reaching, etc. Here we obtain a measure of the representation of hand size that does not rely on judgements of landmarks or other perceptual tasks but rather looks at the hand as a whole and requires making only size judgements.

Previous studies that have explored hand representation usually focused on one side - either the dorsum or the palm (Coelho & Gonzalez, 2019; Longo, 2015b; Longo et al., 2012; Longo & Haggard, 2010; Mancini, Longo, Iannetti, et al., 2011) – but have not considered how the size perception of the two sides of the same body part might correspond. While the perceived sizes of the dorsum and palm have not previously been compared within individuals, previous studies have shown differences between the dorsum and palm for tasks involving localization of cutaneous stimuli (Mancini, Longo, Iannetti, et al., 2011), mental rotation of the hands after experiencing the rubber hand illusion (Ionta et al., 2013), tactile size perception (Longo, Ghosh, et al., 2015; Longo & Haggard, 2011), tactile distance (Knight et al., 2014), position sense (Longo & Haggard, 2012a), pointing to locations of hand and finger landmarks – such as knuckles and fingertips (Longo & Haggard, 2012b) and distances between two fingers (Cocchini et al., 2018).

Longo and Haggard (2012a), in what they referred to as a 2.5-D representation of the human hand (inspired by David Marr (1982)), found clear overestimation of the perceived size of both sides of the hand but the palmar side was significantly less overestimated than the dorsal surface. This was despite the fact that the palm, with its larger number of receptors has a larger representation in the primary somatosensory cortical map than the dorsum (Johansson & Vallbo, 1979). Higher accuracy for the palm may be due to the more orderly, somatotopic representation of glabrous skin (palm) compared with hairy skin (dorsum) which is represented irregularly in islands of cortex intermixed with the map of glabrous skin (Powell & Mountcastle, 1959). Tactile skin perception and position sense (Longo & Haggard, 2011) both show that the implicit representation of the palm is less distorted than that of the dorsum; one might expect that the more accurate representation of the palm would be transferred or extruded to the dorsum if the brain used a single, coherent model of the hand as a volumetric object.

Our study has two motivations. Firstly, to determine how accurate healthy populations are at judging the size of the dorsum and palm of their hand. Based on previous research (Longo, 2015b; Longo et al., 2012; Longo & Haggard, 2010) we predicted that the dorsum would overall be perceived as shorter and wider than it actually was. Secondly, to assess how perception of hand size might be affected when viewing the hand in familiar and unfamiliar perspectives. The hand is more likely to be identified as belonging to the self when viewed in a familiar orientation (Hoover & Harris, 2016; Hoover & Harris, 2015). Our previous rationale for varying the orientation of the face while assessing its perceived size (D'Amour & Harris, 2017) had to do with unique properties that the face lacks compared to much of the rest of the body especially the hands, properties such as interaction, movement, and visual perspective. We used the opposite line of thought in the current study. The hand has all these attributes and uses them to the

greatest extent of any body part, thus making it worthwhile to explore how orientation impacts its perceived size. With all the different positions and forms that the hand can take, it seems natural to consider how perception may change with these varying viewpoints. Why might one assume that measuring it in only a “typical” or “canonical” position would be correct? Life-long experiences of directly interacting with and seeing the hands from multiple different viewpoints may result in greater flexibility and plasticity in how the brain represents and perceives the hand. Thus, unlike for the face, we did not expect that varying orientation would affect the hand’s perceived size.

As in our previous papers (D’Amour & Harris, 2019; D’Amour & Harris, 2017), we included sex and body satisfaction as variables to assess how they might impact body size perception. Since the hand is a relatively neutral body part for weight, shape, and size concerns, we did not have any set predictions about differences that might occur but instead used sex and body satisfaction as exploratory factors to add and extend the existing literature.

3.3. Methods

3.3.1. Participants

40 participants (20 females, mean age 24.43 years, $SD = 9.37$) took part in the experiment. Handedness was assessed with the Edinburgh Handedness Inventory (Oldfield, 1971) to ensure that only those with a strong preference were included (38 right-handers). They were recruited from the York University Undergraduate Research Participant Pool and received course credit for taking part in the study. The experiment was approved by the York Ethics Board and all participants signed informed consent forms. The study was performed in accordance with the Treaty of Helsinki.

3.3.2. Materials/Stimuli

Body dissatisfaction

The Body Shape Questionnaire (BSQ) (Cooper et al., 1987) is a 34-item self-report questionnaire that was developed to assess concerns about body shape and experiences of feeling fat that participants may have experienced within the previous month. Each question uses a scale from 1 (never) to 6 (always) that are added together to obtain a total BSQ score ranging from 34 – 204, with lower scores indicating lower levels of body dissatisfaction and higher scores indicating higher levels of body dissatisfaction. The test was administered before the experiment began to obtain a measure of body dissatisfaction. The total BSQ score was used for correlations. To create categorical groups, participants were divided into high and low groups according to whether their score was above or below the overall mean.

Photographs

Color photographs of the dorsal and palmar surfaces of the participant's dominant hand placed flat against a wall were taken using a digital camera (Canon EOS 10D). Photographs were taken under standardized conditions with the flash on, from midarm to the fingers, from a distance of approximately four feet (122 cm) with no zoom function. The images were then cropped to include only the dorsum or palm and formatted with a white background (Adobe Photoshop CC 2014). These images served as the undistorted "real" images and were used for composing the distorted images. Using a soft tape measure, hand size was measured straight down from the tip of the middle finger to the bottom of the hand, just before the start of the wrist. The size of the image was presented life-size by adjusting the magnification of the image until it

matched the participant's actual hand size. Optical distortions of the lens were confirmed as being less than 0.3% of the width or length of the photograph (given that the other length was set to veridical) using Matlab to assess the amount of distortion.

Distorting the images

Images were presented and distorted using MATLAB (version 2011b) and Psychophysics Toolbox (Brainard, 1997) running on a MacBook Pro. One dimension of the image (either width or length) was distorted (made either bigger or smaller) using a QUEST adaptive staircase psychometric procedure (Watson & Pelli, 1983). The image was viewed in the center of a computer monitor (27-inch Apple display) with the dorsum or palm in one of the four orientations shown in Figure 3.1: (1) upright (0°), (2) to the right (90°), (3) upside down (180°), and (4) to the left (270°). Perceived width and length dimensions were separately measured for the palm and dorsum in each of the four orientations, resulting in a total of 16 conditions.

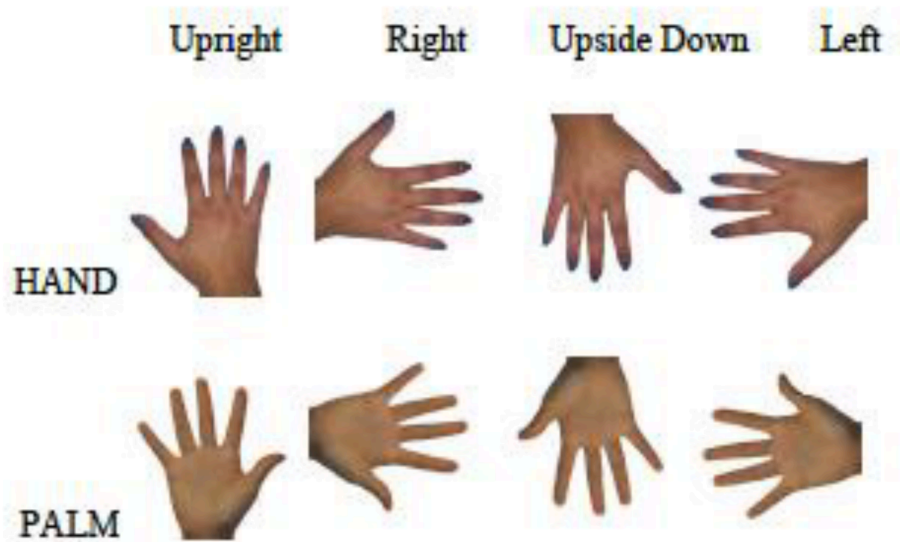


Figure 3.1. Sample images for the dorsum and palm in each orientation used. The four orientations are shown, from left to right, in the order of (1) upright (0°), (2) to the right (90°), (3) upside down (180°), and (4) to the left (270°) for the dorsum (top row) and palm (bottom row).

3.3.3. Procedure

Participants sat in a chair approximately 45 cm in front of the computer screen. To measure perceived size, a two-alternative forced choice (2AFC) design was used. Each trial consisted of two 1.5s intervals – one interval containing the undistorted image and one interval containing the distorted image - separated by a blank white screen for 1.5s. Participants identified which interval contained the image that most closely matched the perception of their own hand and responded using a two-button computer mouse (left button for first interval, right button for second interval). Two interleaved QUEST staircases (25 trials per staircase) were used for each condition (50 trials total), with one starting with the manipulated dimension 40% larger than the undistorted image and the other starting with that dimension 40% smaller than the undistorted image. The standard deviation of the guess was set to 60% as the authors (Watson & Pelli, 1983) suggest a liberal standard deviation to improve accuracy. Each of the 16 conditions were run in a single block and took approximately six minutes to complete. Block order was determined by a Latin square and was counterbalanced across participants.

3.3.4. Data Analysis

The QUEST program returned an estimate of the distortion at which the participant reported that the distorted image was equally like their perceived body size as the undistorted image. The QUEST algorithm assumes the observer's psychometric function follows a Weibull distribution and adaptively determines the amount of distortion to be presented based on the participant's response to the previous trials. As the experiment goes on, knowledge on the observer's psychometric accumulates. To visualize and confirm the QUEST's performance, the

participant's decision was plotted against the distortion used for each trial and fitted with a logistic (Equation 3.1) using the curve fitting toolbox in MATLAB.

$$\text{Decision} = 1/(1+\exp(-(x-x_0)/b)) \dots\dots\dots (3.1).$$

where x_0 is the actual size, x is the distorted value that was equally likely to be judged as matching the observer's size, and b is an estimate of the slope of the function. The size of the internal body representation was taken as the point halfway between x and x_0 .

All of the participants' data for each condition were examined to validate the accuracy and efficiency of the QUEST procedure. The QUEST's performance was also checked to determine whether reliable estimates were obtained within 50 trials. All data were inspected for outliers. Outliers were defined as points that fell outside ± 3 standard deviations from the mean. Data that failed to meet these criteria were discarded from the analyses (0 participants).

Estimates were converted to percentages relative to the accurate reference photograph. For the two left-hand participants, the data for the right and left orientations were switched to correspond to the correct position. Data analyses were conducted on these values using SPSS 23. Correlations and mixed measures analyses of variances (ANOVAs) were used for statistical analyses, with alpha set at $p < .05$ and post-hoc multiple comparisons were made using Bonferroni corrections.

3.4. Results

Data in only one out of 16 of the conditions were significantly correlated with BSQ score so BSQ groups were not included in the analyses.

3.4.1. Dorsum and Palm Size Accuracy: Width Dimension

Figure 3.2 shows the results for perceived width of the dorsum and palm. A three-way mixed ANOVA was conducted to test for the within-subjects effects of body part (dorsum or palm), orientation (upright, right, upside down, and left), and the between-subjects effect of sex (male and female). The only significant effect found was for orientation, $F(3, 114) = 3.44$, $p = .018$, $\eta_p^2 = .083$, with pairwise comparisons showing that upright ($M = .97$, $SE = .95$) and right ($M = -1.82$, $SE = .67$) orientations differed by $2.79\% \pm .98$, $p = .044$, 95% $CI = [.05, 5.53]$.

3.4.2. Dorsum and Palm Size Accuracy: Length Dimension

A second ANOVA was conducted using the same variables as above but for the length dimension (Figure 3.3). A significant main effect was found for body part, $F(1, 38) = 8.68$, $p = .005$, $\eta_p^2 = .186$, with greater amounts of distortion observed for the dorsum of the hand ($M = 2.26$, $SE = .94$) compared to the palm ($M = .30$, $SE = .74$). This means that participants were less accurate at judging the length of their dorsum but were not significantly different from perfect accuracy for the palm.

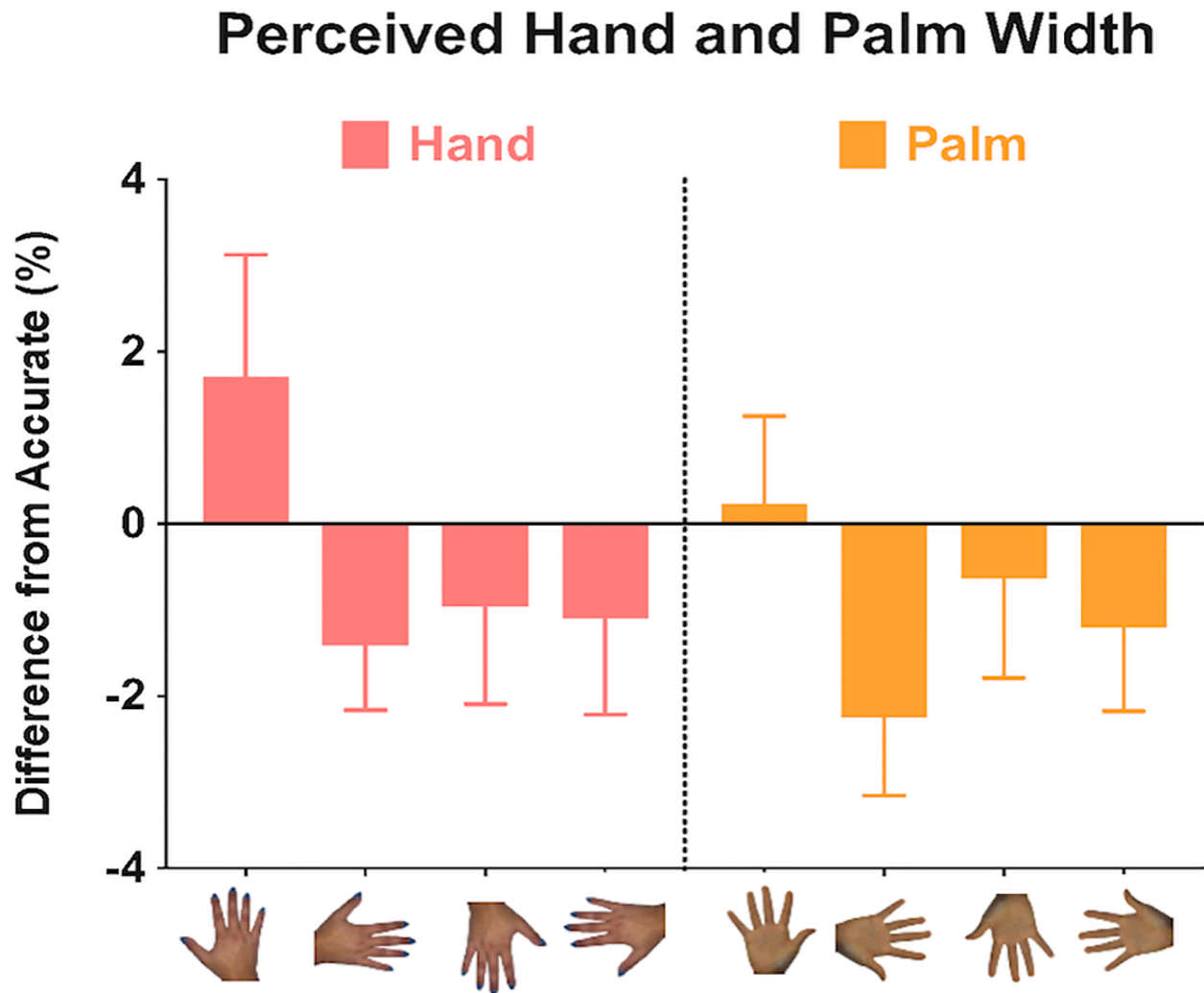


Figure 3.2. Perceived width of the dorsum and palm. Mean differences from accurate when dorsum of the hand (left panel) or palm (right panel) was distorted in the width dimension for each viewing orientation. Positive and negative scores represent overestimation and underestimation respectively. Error bars represent ± 1 SEM.

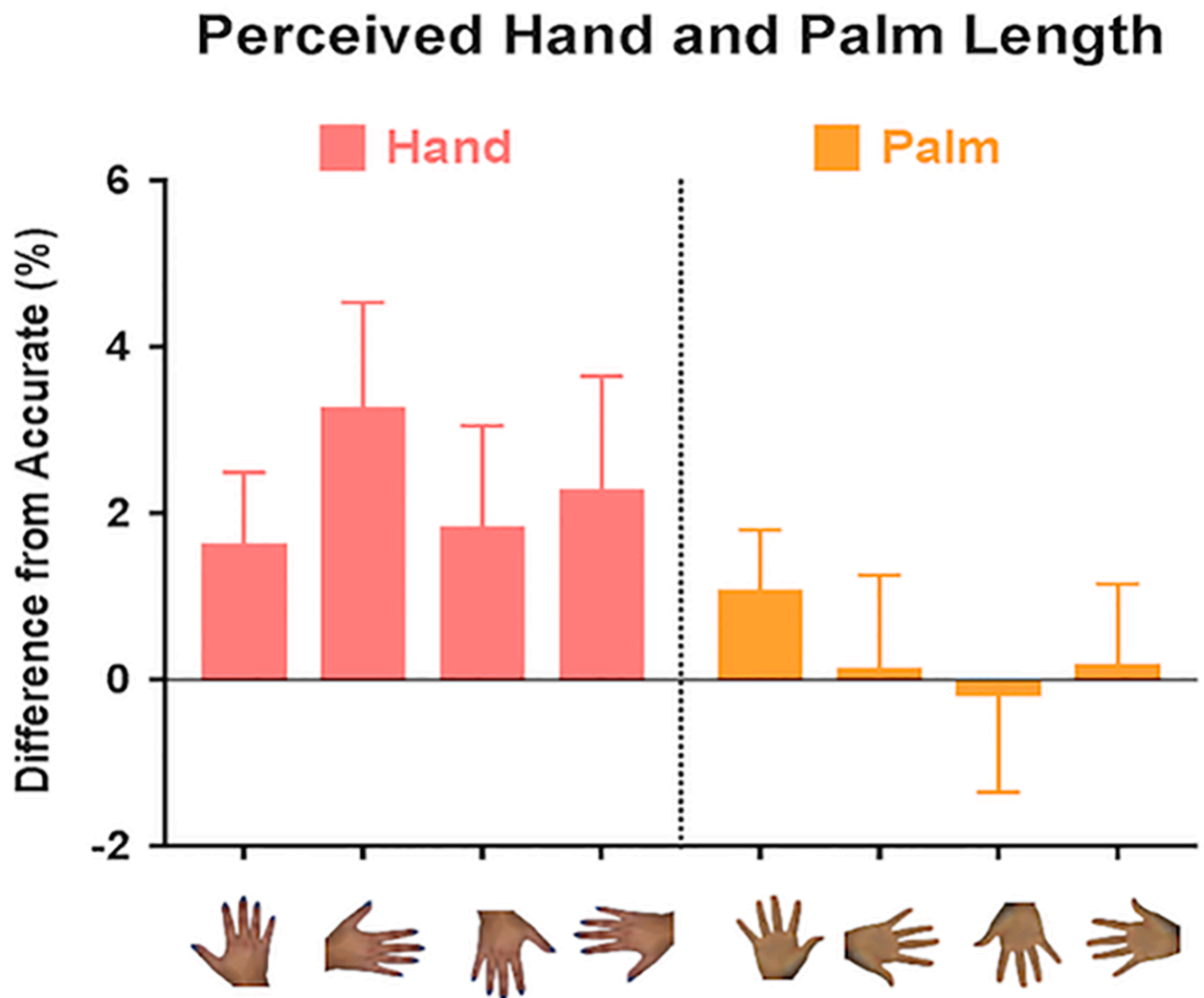


Figure 3.3. Perceived dorsum and palm length. Mean differences from accurate when dorsum (left panel) or palm (right panel) was distorted in the length dimension for each viewing orientation. Positive and negative scores represent overestimation and underestimation respectively. Error bars represent ± 1 SEM.

3.4.3. Relationship between Dorsum and Palm

Correlations between errors in the perceived size of the dorsum and palm (Table 3.1) were conducted for width and length (averaged across the four orientations in Figure 3.4). The width of the dorsum and palm were significantly correlated, $r(39) = .550$, 95% $CI = [.29, .74]$, $R^2 = .302$, $p < .001$, as were the length of the dorsum and palm, $r(39) = .708$, 95% $CI = [.51, .84]$, $R^2 = .502$, $p < .001$. These results show that there was a strong relationship between the perceived size of the dorsum and palm— if someone overestimates their dorsum size, they will likely overestimate their palm size as well.

Table 3.1

Correlations between the perceived size of the dorsum and palm (N = 40).

Dorsum vs Palm		Pearson r	p	95% CI
Width	Combined	.550	.000 **	[.29, .74]
	Upright	.157	.334	[-.16, .45]
	Right	.234	.146	[-.08, .51]
	Upside Down	.298	.062	[-.02, .56]
	Left	.243	.131	[-.08, .52]
Length	Combined	.708	.000 **	[.51, .84]
	Upright	.284	.076	[-.03, .55]
	Right	.304	.057	[-.01, .56]
	Upside Down	.365	.021 *	[.06, .61]
	Left	.505	.001 **	[.23, .71]

* $p < .05$. ** $p < .01$.

Hand vs Palm

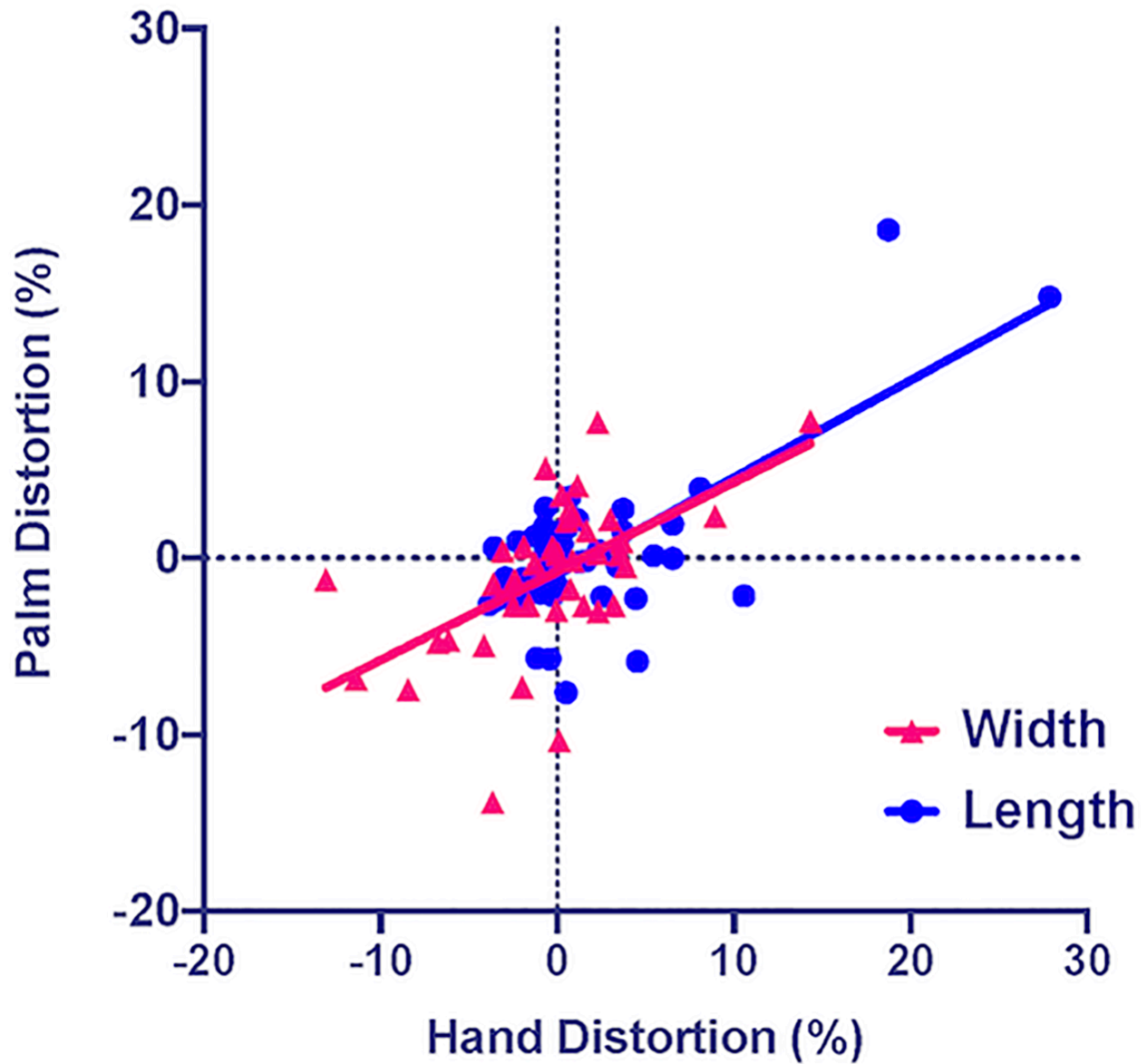


Figure 3.4. Dorsum vs palm. Relationship between dorsum and palm distortions for width (pink triangles) and length (blue circles). The lines plotted through the data are the goodness-of-fit lines for the width and length.

3.4.4. Actual vs Perceived Size

To see how the distortion percentages would look when calculated relative to actual size, we calculated the perceived lengths of the dorsum and palm (averaged across the four orientations) to make our results more clearly understandable and relatable to previous studies. Figure 3.5 shows the perceived length of (Figure 3.5A) the dorsum ($M = 7.31$ inches, $SE = .12$) and (Figure 3.5B) palm ($M = 7.27$ inches, $SE = .11$) plotted as a function of actual length (dorsum: $M = 7.14$ inches, $SE = .07$; palm: $M = 7.24$ inches, $SE = .08$). The perceived length was significantly different from the actual length for the dorsum, $t(39) = 2.37$, $p = .023$, $\eta_p^2 = .125$, with people perceiving their dorsum to be longer than it actually was by $.17$ inches $\pm .07$, 95% $CI = [.02, .32]$. There was no significant difference between the perceived and actual length of the palm, $t(39) = .57$, $p = .573$, $\eta_p^2 = .008$.

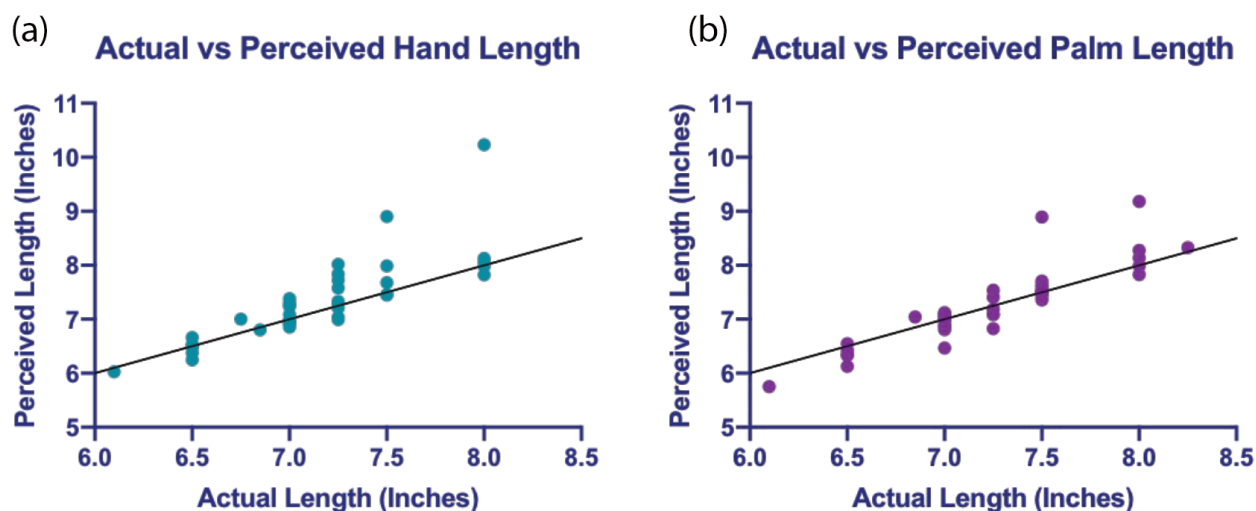


Figure 3.5. Actual vs perceived length. Relationship between actual and perceived lengths for (A) dorsum length and (B) palm length. The line plotted through the data represents accurate perception.

3.5. Discussion

The method we used here reveals distortions of the implicit body representation independent of the conscious body image. The length of the representation of the dorsum and palm of the hand were significantly different from each other but only the perceived width of the dorsum depended on orientation with overestimation found when the dorsum was viewed upright and an underestimation when viewed in the right orientation. The representations of the dorsum was longer than its actual size. The dorsum and palm did not show any differences for width judgements. Accuracy differed between the dorsum and the palm in the length dimension, meaning that the perceived length of the dorsum and palm were not the same although there was a strong correlation between them.

Perception of the size of the dorsum and palm reveals distortions in how the body is represented in the brain. The enormous distortions in the homunculus of the primary somatosensory cortex are largely corrected (Penfield & Boldrey, 1937) but for every orientation, dorsum length was overestimated whereas the length of the palm was perceived accurately. This is curious as it is the dorsum that is more usually seen (look down at your hands as they type on your computer right now). However, this makes sense in terms of function, as it is the location of the fine-tuned receptors on the palm side of your fingertips (Weber, 1996) that it is important that you place in the correct positions.

3.5.1. Comparisons to Previous Findings

Overestimations of hand width, underestimation of finger length, and a radial-ulnar gradient of magnification, with finger length underestimation increasing from thumb to little finger were found by Longo & Haggard (2010). Longo & Haggard (2011) confirmed these

findings and also showed that the width of both the dorsal and palmar surfaces were overestimated whereas only finger length was underestimated for the dorsal surface. These findings differ from our current findings but there are many explanations for why this might be – 1) our methods are extremely different including the design, task, and measures obtained; 2) they measured hand width using the distance between the bases of the index and little fingers; 3) they only looked at finger length rather than the length of the entire hand and palm. In fact, no distortions were found when they tried using a template matching task to see how it would compare to their original findings (Longo, 2015d; Longo & Haggard, 2010; Longo & Haggard, 2012b).

3.5.2. Sex and Body Satisfaction Scores

Since sex (Gleghorn et al., 1987; Molinari, 1995; Slade & Russell, 1973; Thompson & Spana, 1988) and body satisfaction (Eshkevari et al., 2012; Gardner & Bokenkamp, 1996; McCabe et al., 2006; Mussap et al., 2008) are known to be factors that influence body perception, we looked at both variables in our current study but surprisingly did not find effects of either.

Our findings that there are no differences between how males and females perceive their hand size is not compatible with what has been found in previous studies that looked at sex differences in hand representation (Coelho & Gonzalez, 2019; Longo, 2019). Longo (2019) recently conducted a meta-analysis of nineteen experiments that used his ‘psychomorphometric paradigm’ method of mapping the body (Longo & Haggard, 2010) to examine whether sex differences exist for perceptual hand maps. He concluded that distortions occurred for both males and females but that sex differences exist in the magnitude of distortions in perceptual hand

maps, with women showing greater overestimation of hand width and men showing greater underestimation of finger length. This differs from what Coelho & Gonzalez (2019) found. They found that finger length was underestimated in both sexes, but hand width was only overestimated in women. Longo (2019) speculates that these differences could be explained by how actual hand size (used as a reference) was measured – using a photograph of the hand next to a ruler in his studies compared to Coelho and Gonzalez’s method of pointing to landmarks on a non-occluded hand. The latter may not provide an accurate reference due to potential motor control or visual biases with which such localization tasks may be associated. Again, the fundamental differences between our experimental methods and how the hand was measured could be the cause (e.g., hand width and finger length) since our method asks people to access their internal representation.

3.5.3. Conclusions

Knowledge about body size is important for many aspects of perception and action that rely on this information for executing and interpreting tasks, especially for the hands that are required for so many fundamental behaviours (reaching, grasping, touching, holding, etc.,). Distortions in how the brain represents the hand may impact these processes and result in errors that have far-reaching consequences.

3.6. Acknowledgments

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CHAPTER 4:

The Representation of Body Size: Variations with Viewpoint and Sex

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4.1. Abstract

Perceived body size is a fundamental construct that reflects our knowledge of self and is important for all aspects of perception, yet how we perceive our bodies and how the body is represented in the brain is not yet fully understood. In order to understand how the brain perceives and represents the body, we need an objective method that is not vulnerable to affective or cognitive influences. Here, we achieve this by assessing the accuracy of full-body size perception using a novel psychophysical method that taps into the implicit body representation for determining perceived size. Participants were tested with life-size images of their body as seen from different viewpoints with the expectation that greater distortions would occur for unfamiliar views. The Body Shape Questionnaire was also administered. Using a two-alternative forced choice design, participants were sequentially shown two life-size images of their whole body dressed in a standardized tight-fitting outfit seen from the front, side, or back. In one image, the aspect ratio (with the horizontal or vertical dimension fixed) was varied using an adaptive staircase, while the other was undistorted. Participants reported which image most closely matched their own body size. The staircase honed in on the distorted image that was equally likely as the undistorted photo to be judged as matching their perception of themselves. From this, the perceived size of their internal body representation could be calculated. Underestimation of body width was found when the body was viewed from the front or back in both sexes. However, females, but not males, overestimated their width when the body was viewed from the side. Height was perceived accurately in all views. These findings reveal distortions in perceived size for healthy populations and show that both viewpoint and sex matter for the implicit body representation. Though the back view of one's body is rarely - if ever -

seen, perceptual distortions were the same as for the front view. This provides insight into how the brain might construct its representation of three-dimensional body shape.

Keywords: Body representation, perceived size, full body perception, viewpoint, perceptual size distortions, height, body width

4.2. Introduction

The body is such an important part of our life – without it, we would not even exist. We use our body to present ourselves and to perceive and interact in the world. Knowledge about body posture, position, size, and structure are required to interpret and react to sensory information that is constantly being received and that may be coded relative to the body (Harris et al., 2015; Kopinska & Harris, 2001). Processing sensations and generating actions requires the brain to accurately map and represent the body and the body-in-space. However, the first-person perspective of the body is highly restricted, and the third-person perspective afforded by a mirror provides only a limited view. We cannot directly see our entire body in the same way that we can view the entirety of our hands, arms and legs. However, it is the full three-dimensional body that is represented in the brain (Kammers et al., 2009; Longo & Haggard, 2012b). How is the brain able to form such a representation of the body when it is not able to see it from multiple viewpoints? How accurate is its representation? The question then becomes focused on body perception when seen in unfamiliar views, such as from the side or back, to better understand how the implicit body representation is built up in the brain. We aim to answer these questions by assessing how accurate people are at judging their full body size when viewing their body from various viewpoints of which only the frontal view would be familiar. We used our novel psychophysical method that provides an implicit measure of the internal body representation (D'Amour & Harris, 2017). Our method involves a participant choosing which of two images is most like their own body and adjusting one of the images accordingly. It ends when both images (reference and distorted) are equally likely to be chosen, neither of which actually matches their body representation. The representation is calculated as being between these values.

Body size perception has typically been looked at in those suffering from eating disorders as distortions and disturbances of perceived body size and shape most obviously occur in these populations (Gardner & Brown, 2014; Molinari, 1995; Probst et al., 1995). Such studies have often tended to focus on measuring body image – how one feels about one’s body from a cognitive, emotional, and subjective view – rather than looking at how the brain internally maps and represents the body,

The objective of the current study was to examine perceived full body size accuracy to determine baseline values of how distorted the brain’s representation might be in a healthy, young populations of both males and females. The perceived width and height of the full body was measured as seen from three different body viewpoints in order to assess how the accuracy of perception changes when the image is presented in familiar and unfamiliar views. Previous studies have suggested both men and women tend to overestimate body width (Dolan et al., 1987) and have emphasized the importance of baseline judgements in the healthy population (Sadibolova et al., 2019a). However, until the introduction of virtual avatars, most studies have used smaller-than-life-size photographs which confound absolute judgements with aspect ratio judgements and perhaps explains why perceived height, which requires the use of full-size images, has been neglected. Estimates of people’s perception of their height have tended to come from actions, such as ducking under barrier (Stefanucci & Geuss, 2012) which may not correspond to perceptual measures. In photographs height tends to be underestimated (Kato & Higashiyama, 1998). We hypothesized that there would be significant deviations from accurate in our healthy population, with the body being perceived as bigger and also as shorter than its actual size, with greater distortions for body width.

There is a trend in this area of research to use images of the body as seen from the front – corresponding to the view most commonly seen in the mirror. However, being overweight is most obvious in the profile view: a view which can only be imagined without a complex arrangement of mirrors. There is thus a potential for a richer source of information from judgements of the body seen in side view (Cohen, Bernard, et al., 2015; Cohen, Ndao, et al., 2015; Swami & Tovée, 2007). We therefore predicted that there would be a difference between viewpoints. Familiar views (as seen in a mirror) were expected to be more accurate than unfamiliar views (side and back views that rely on a person's imagination to visualize), so that the front view would be the most accurate and the back and side views would be the least accurate.

Sex and body satisfaction were also assessed to see how these factors might impact perceived body size. Men and women show different patterns of perceived body distortion with women being more prone to judge themselves as fatter (Fallon & Rozin, 1985; Feingold & Mazzella, 1998; Thaler et al., 2018). This asymmetry may even have a basis in the differential roles of the cortical hemispheres in the representation of the body (Mohr et al., 2007). Differences related to both sex and body satisfaction were therefore anticipated, with females and those with higher levels of body dissatisfaction showing greater perceptual distortions. Previous studies looking at body size perception have tended to concentrate on females (Cornelissen et al., 2017; Gleghorn et al., 1987; Molinari, 1995; Slade & Russell, 1973; Thompson & Spana, 1988); but see (Craig & Caterson, 1990; Dolan et al., 1987; Stephen et al., 2018). Thus, there is a relative lack of knowledge about how males represent their bodies and whether they might also show distortions in size perception. Here, we included both males and females. While previous research has shown that perceptual body distortions occur more in those

dissatisfied with their bodies (Cash & Deagle, 1997; Cornelissen et al., 2013; Hrabosky et al., 2009; Mai et al., 2015; Mohr et al., 2011; Probst et al., 1998; Sand et al., 2011; Stice & Shaw, 2002), these studies have also focused on clinical eating disorder populations with high levels of body dissatisfaction and have often overlooked the healthy population. Based on these previous findings, we thought that there would be differences between low and high body dissatisfaction groups. We expected to find greater distortions for those in the high body dissatisfaction group, especially for the width conditions than for those in the low body dissatisfaction group. We also predicted that there would be strong positive correlations between body dissatisfaction and perceived size distortions.

4.3. Methods

4.3.1. Participants

Thirty-seven participants (18 females and 19 males) took part in the experiment (mean age = 21.24 years, SD = 7.61; mean BMI = 23.75, SD = 4.09; mean weight = 68.94kg, SD = 14.39kg; mean height = 169.93cm, SD = 7.52cm; mean BSQ = 85.27, SD = 33.15). They were recruited from the York University Undergraduate Research Participant Pool and received course credit for taking part in the study. The protocol was approved by the York Ethics Board. All subjects gave written informed consent in accordance with the Declaration of Helsinki.

4.3.2. Materials/Stimuli

Body dissatisfaction

The Body Shape Questionnaire (BSQ) (Cooper et al., 1987) is a 34-item self-report questionnaire that was developed to assess concerns about body shape and experiences of feeling

fat that participants may have experienced within the previous month. The test was administered before the experiment began to obtain a measure of body dissatisfaction. Higher scores indicate higher levels of body dissatisfaction. Participants were divided into high and low groups defined as whether their score were above or below the overall mean score.

Photographs

Color photographs of each participant's whole body in standardized poses were taken using a digital camera (Canon EOS 10D; flash on; no zoom function) from each of three different viewpoints with a camera distance of 270 cm. Participants were asked to stand in front of a white wall in three standardized poses. Standardized outfits were provided to obtain accurate outlines of their size and shape (see Figure 4.1). The images were then corrected for any lens distortions, cropped to include only the whole body, and formatted on a white background (Adobe Photoshop CC 2014). These images served as the undistorted reference images and were used for composing distorted images. Actual body height was measured from the bottom of the feet to the top of the head using a ruler taped up to a wall. The image was presented life-size projected (using a BenQ 1080p short throw projector) onto a screen at a viewing distance of 270 cm by digitally adjusting the magnification of the image until it physically matched the participant's actual body size. The viewing distance was chosen as matching the camera's focal length multiplied by the magnification (Cooper et al., 2012) which minimizes distortions.

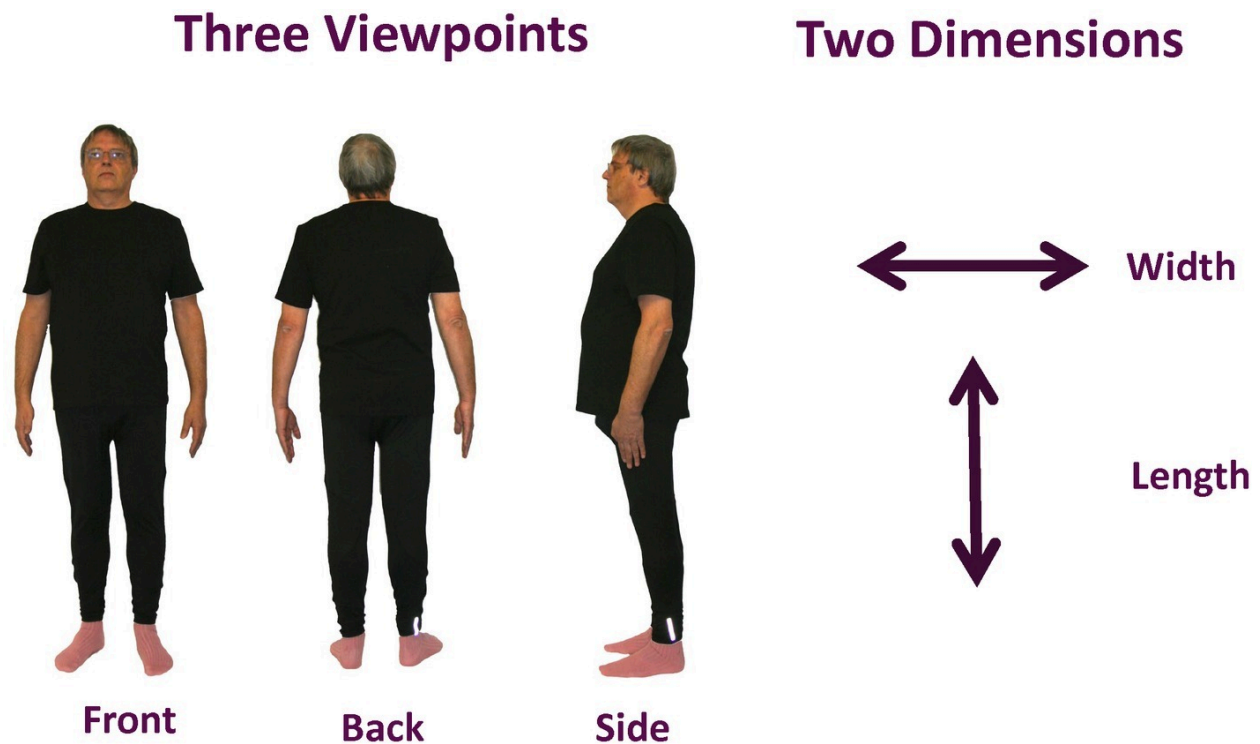


Figure 4.1. Experimental design and conditions. Sample images of the full body are shown for each viewpoint: front, side and back. Width and length dimensions (indicated on the right of the figure) were distorted separately for each of the three viewpoints.

Distorting the images

Images were presented and distorted using MATLAB (version 2011b) and Psychophysics Toolbox (Brainard, 1997) running on a MacBook Pro. One dimension of the image (either width

– see Figure 4.2A - or length – see Figure 4.2B) was distorted (made either bigger or smaller) using a QUEST adaptive staircase psychometric procedure (Watson & Pelli, 1983). The image was viewed in the center of a projector screen with the full body shown from one of three viewpoints: (1) front, (2) side or (3) back. Perceived width and height were measured separately for each viewpoint so there was a total of six experimental conditions.

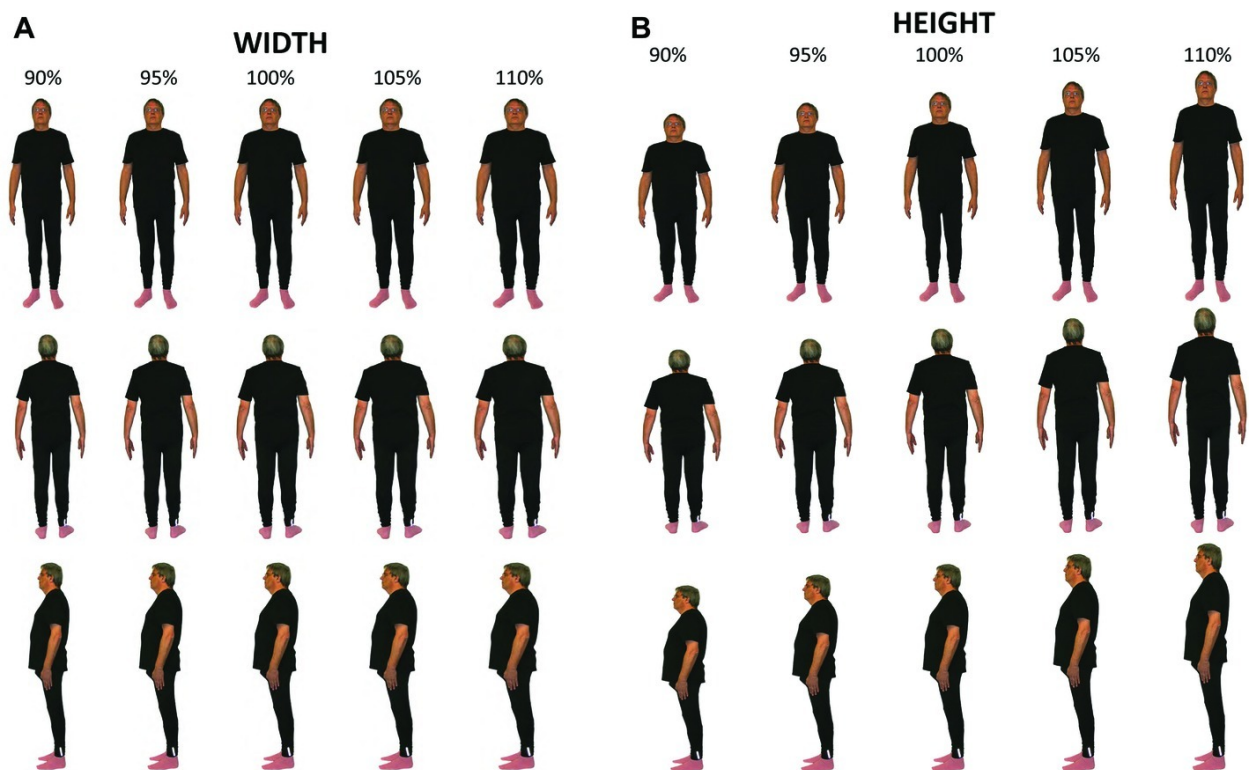


Figure 4.2. Examples of distorted images. Sample images of the distorted full body are shown for the (A) width and (B) height for each viewpoint - front, side and back.

4.3.3. Procedure

Participants sat in a chair at a viewing distance of 270 cm from the projector screen. Each trial consisted of two 1.5s intervals – one interval containing the undistorted image and one interval containing the distorted image presented in a random order - separated by a blank white screen for 1.5 secs. Participants identified which interval contained the image that most closely matched their perception of their own body and responded using a two-button computer mouse (left button for first interval, right button for second interval). A QUEST adaptive staircase procedure (Watson & Pelli, 1983) was used with a two-alternative forced choice (2AFC) design to vary the chosen dimension (length or width) of the distorted image (D'Amour & Harris, 2017). Two interleaved QUEST staircases (25 trials per staircase) were used for each condition (50 trials total), with one starting with the manipulated dimension larger than natural and the other starting with that dimension smaller than natural. Each of the six conditions were run in a single block and took approximately six minutes to complete. Condition order was determined by a Latin square and was counterbalanced across participants.

4.3.4. Data Analysis

The QUEST program returned an estimate of the percentage distortion relative to the undistorted at which the participant reported that the distorted image was as like their perceived body size as the undistorted image. The QUEST algorithm assumes the observer's psychometric function follows a Weibull distribution and adaptively determines the amount of distortion to be presented based on the participant's response to the previous trials. As the experiment goes on, knowledge on the observer's psychometric accumulates. Participant's decisions were plotted

against the distortion used for each trial and fitted with a logistic (Equation 4.1) using the curve fitting toolbox in MATLAB.

$$\text{Decision} = 1/(1+\exp(-(x-x_0)/b)) \dots\dots\dots (4.1).$$

where x_0 is the distorted value that was equally likely to be judged as matching the observer's size as the undistorted photograph, and b is an estimate of the slope of the function. The size of the internal body representation was taken as the point half way between x_0 and the accurate size. We then subtracted 100% from this value to derive a difference-from-accurate score where positive numbers corresponded to an overestimate and negative numbers to an underestimate. The values so obtained for each participant for each condition were examined for outliers, defined as falling outside ± 3 standard deviations from the mean. If a value fell outside this range (3 participants – 2 females, 1 male) the complete dataset for that participant was removed.

One-sample t tests were conducted for each condition to assess whether difference-from-accurate values significantly differed from zero (accurate). Mixed measures analyses of variances (ANOVAs) were used for statistical analyses, with alpha set at $p < .05$ and post-hoc multiple comparisons were made using Bonferroni corrections. Pearson correlations were used to determine the relationship between body dissatisfaction and accuracy. Since we had predicted that there would be a specific direction for the correlations, one-tailed p -values were used.

4.4. Results

4.4.1. Full Body Size Accuracy

Table 4.1 summarizes the results of t-tests showing that the perceived width when seen from the front and side viewpoints were significantly different from accurate.

Table 4.1

One-Sample t-Tests Comparing Mean Accuracy Errors (percentage distortions) to accurate (zero distortion).

		<i>M (SEM)</i>	<i>t</i> (33)	<i>p</i>	95% CI
Width	Front	-3.15 ± 1.32	-2.39	.023 *	[-5.84, -0.46]
	Side	-0.83 ± 1.29	-0.64	.524	[-3.45, 1.79]
	Back	-2.85 ± 1.14	-2.49	.018 *	[-5.18, -0.52]
Length	Front	-0.71 ± 0.87	-0.82	.420	[-2.47, 1.05]
	Side	-0.07 ± 0.87	-0.08	.934	[-1.85, 1.71]
	Back	0.34 ± 0.91	0.37	.714	[-1.51, 2.18]

Note. *N* = 34. SEM = standard error of the mean. CI = confidence interval.

**p* < .05. ** *p* < .001.

4.4.2. Full Body Size Accuracy: Width Dimension

A three-way mixed ANOVA was conducted to test for within-subject effects of viewpoint (front, side, and back), and between-subject effects of sex (male and female) and BSQ group (low and high) for the width dimension (Figure 4.3). A significant main effect of viewpoint, $F(2, 60) = 3.38, p = .040, \eta_p^2 = .101$, and a significant interaction between viewpoint and sex, $F(2, 60) = 3.77, p = .028, \eta_p^2 = .112$, were revealed. There was a difference in how width was perceived for the side view, with females showing greater overestimation from the side compared to both the front ($p = .017$) and back ($p = .006$) views with no significant difference between front and back views. Females' side view estimates differed from male side view estimates ($p = .019$) with males underestimating their width in side view and females overestimating it. No interaction effects were found between viewpoint and BSQ group, $F(2, 60) = .90, p = .413, \eta_p^2 = .029$, or between viewpoint, sex, and BSQ group, $F(2, 60) = .56, p = .576, \eta_p^2 = .018$. There were no significant findings in any of the between-subjects effects tests.

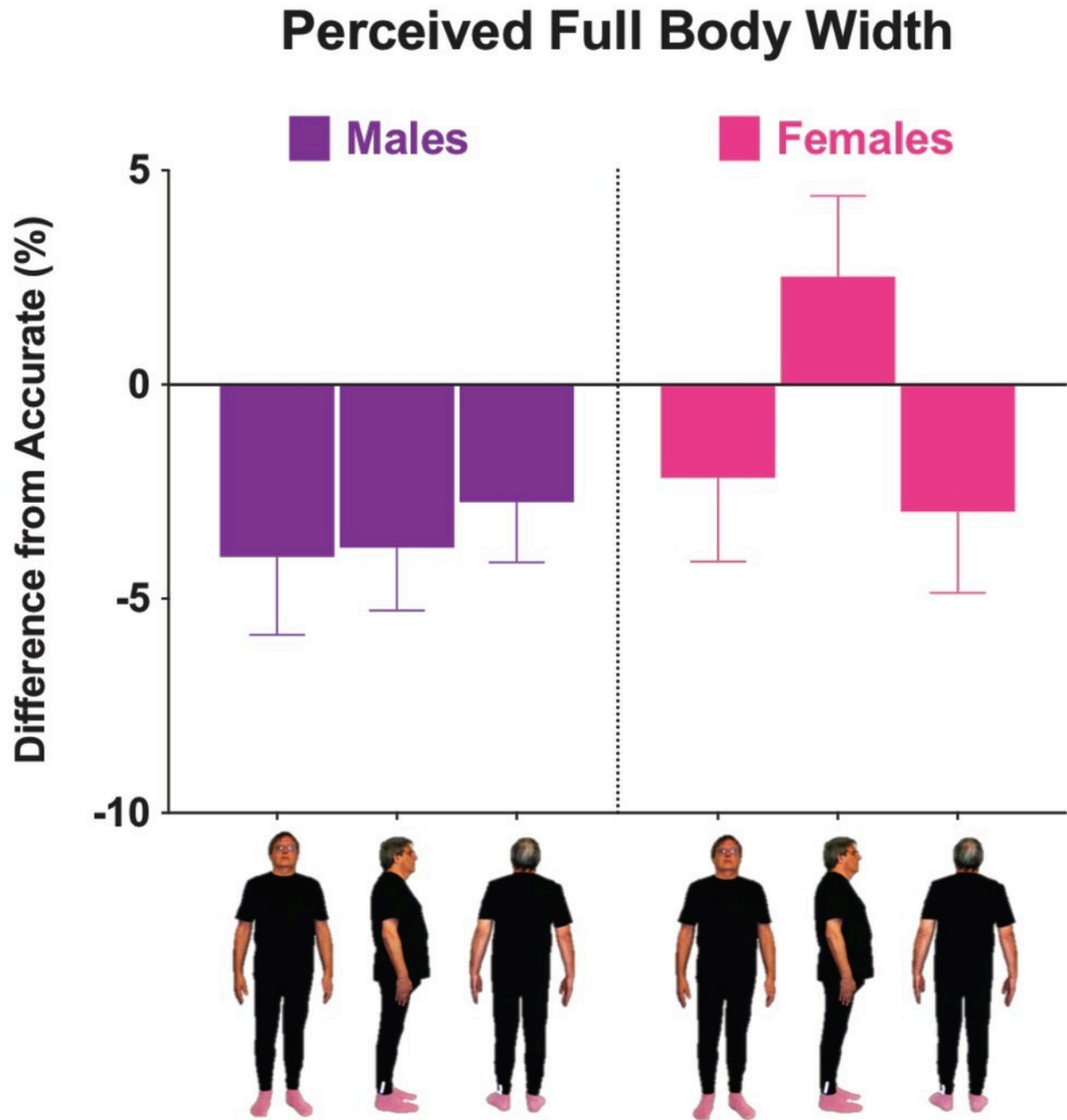


Figure 4.3. Mean differences from accurate for males (left panel) and females (right panel) when body width was distorted for each viewpoint. Positive and negative scores represent overestimation and underestimation respectively. Error bars represent ± 1 SEM.

4.4.3. Full Body Size Accuracy: Length (height) Dimension

A second ANOVA was conducted using the same variables as above for the length (height) dimension (Figure 4.4). No significant main effects or interactions were found for the within-subjects effects tests. This suggests that perceived body length (height) was not impacted by seeing the body in different views. However, there was a significant interaction between sex and BSQ group, $F(1, 30) = 7.51$, $p = .010$, $\eta_p^2 = .200$. The high BSQ group differed ($p = .026$) in the distortion direction for males (overestimate: $M = 2.71$, $SE = 1.72$) and females (underestimate: $M = -2.59$, $SE = 1.46$). There were also non-significant trends when the high and low BSQ groups were compared for each sex (males: $p = .075$; females: $p = .051$).

Perceived Full Body Length

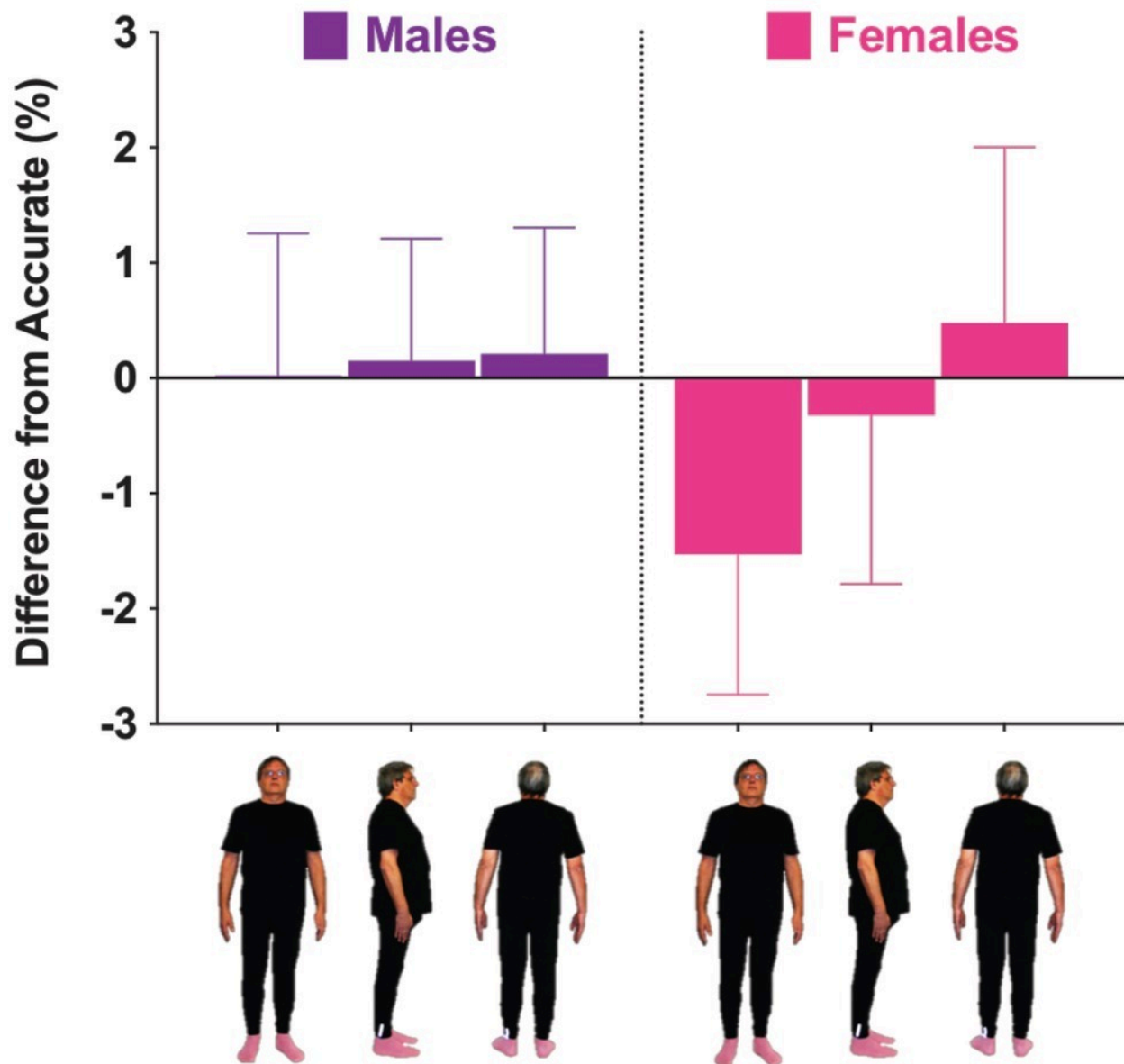


Figure 4.4. Mean differences from accurate for males (left panel) and females (right panel) when body length (height) was distorted for each viewpoint. Positive and negative scores represent overestimation and underestimation respectively. Error bars represent ± 1 SEM.

4.4.4. Correlations between Perceived Full Body Size Accuracy and BSQ Scores

Pearson correlations were run on the BSQ scores and differences-from-accurate to determine the relationship between body dissatisfaction and perceived size judgments. For the width dimension (Figure 4.5), there was a strong and significant correlation for the front view, $r(33) = .310, p = .037$, and the side view, $r(33) = .349, p = .022$, but no relationship was found for the back view, $r(33) = .099, p = .289$. There were no significant correlations between perceived size accuracy and BSQ score for the length (height) dimension (front: $r(33) = -.193, p = .138$; side: $r(33) = -.077, p = .333$; back: $r(33) = -.100, p = .287$).

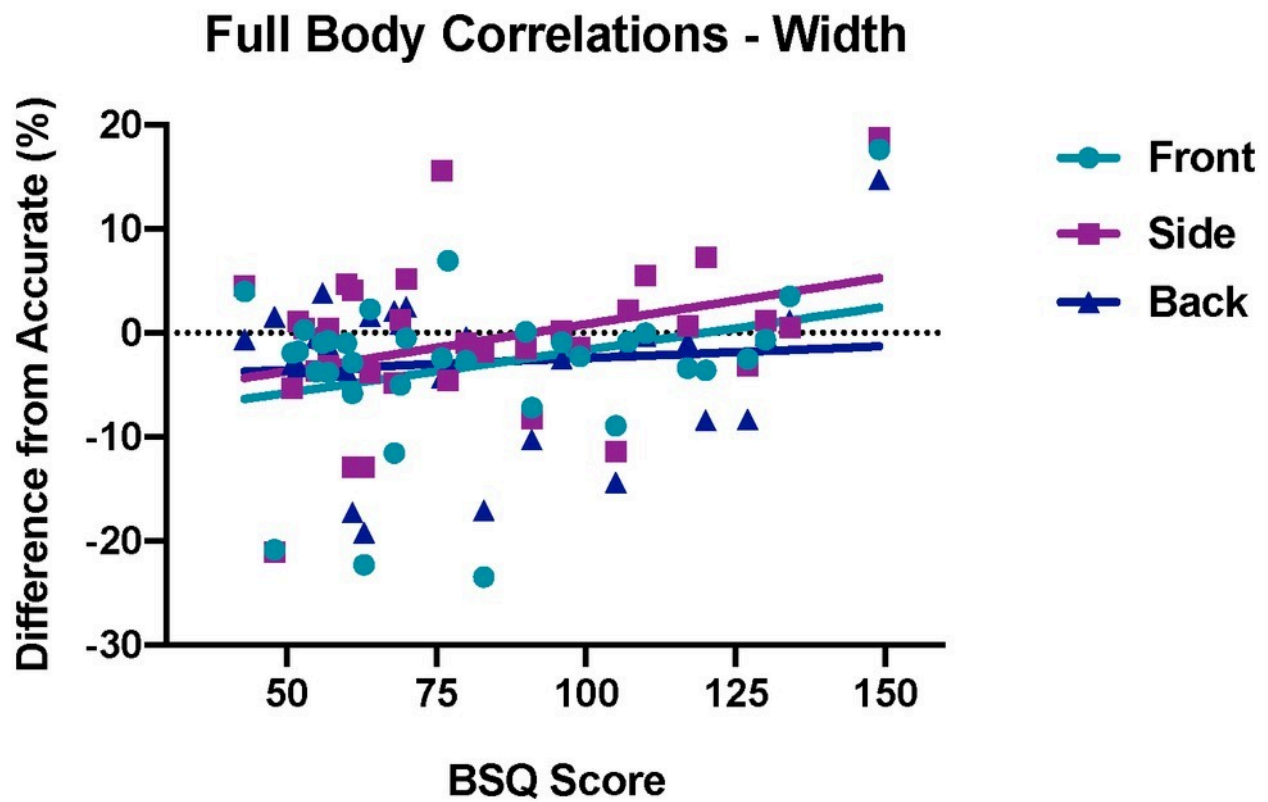


Figure 4.5. Correlations between BSQ score and differences from accurate for perceived body width for the front (blue circles), side (purple squares), and back (dark blue triangles) viewpoints ($n = 34$). The solid lines through the data represent linear regression fits.

4.5. Discussion

Width and length were measured for the full body from the front, side, and back view in order to obtain baseline accuracy values in a healthy population of males and females. We found that the full body was perceived as thinner (underestimating width) in the front and back views but when the body was viewed from the side, only females overestimated their width. A parallel can be found in emerging sex differences in hand perception where overestimation of hand width is larger in females (Coelho & Gonzalez, 2019; Longo, 2019). The height of the body was perceived as accurate. Our results reveal that viewpoint, sex, dimension (height/width), and body satisfaction matter for body representation. These findings provide insights into the mechanisms and factors that are involved in understanding how the body is processed, represented, and perceived.

4.5.1. Overall Accuracy

Our finding that, independent of sex or body dissatisfaction, full body size was perceived as different from actual size when viewed from the front and side view when measured using a rigorous psychophysical method, is a novel finding that adds to the literature about body size accuracy in healthy populations. These results provide baseline measurements of distortions in full body perception at the level of the brain's implicit body representation. The underestimations in body width that we observed have also been shown in some previous studies (Gardner et al., 1989). The finding that height was perceived accurately in all cases was unexpected because we make continual changes and adjustments to alter the height of our bodies at least as perceived by others such as by wearing heeled shoes, donning hats, and often by styling our hair. A unique feature of this study was that we used life-size photographs which is necessary to measure

perceived height. While previous studies have looked at height estimation, they have typically used methods that require participants to make judgements based on apertures or barriers (Stefanucci & Geuss, 2012; Wignall et al., 2017) but these indirect measures cannot be applied to understanding the accuracy of the internal representation of body height.

4.5.2. The Effect of Viewpoint

Front and Back View

Our predictions about the effects of viewpoint turned out to be the opposite of what we found. There was a general tendency to underestimate body width for males and females in accordance with Mazzurega et al.'s self-serving bias (Mazzurega et al., 2018). Interestingly, the front view (the view that we often see in a mirror) and the back (a view that we never see) showed the same distortions. And instead of familiar views being the most accurate, the front view actually showed the greatest amount of distortions. This may be further support for the special relationship that the front and back of the body have with each other. The representations of the front and back of the body may be mapped together by the brain (D'Amour & Harris, 2014; Harris et al., 2015; Hoover & Harris, 2015; Parsons & Shimojo, 1987; Tamè et al., 2016). Thus, any distortion of one would be reflected in a comparable distortion of the other (see Figure 4.3).

Side View

Females perceived themselves to be wider than actual size only in the side view reminiscent of the female-only “fatter bias” of Mohr et al. (2007). There are several possible reasons for this. The side view is rarely if ever seen and therefore is most demanding on the

viewer's ability to visualize this view using only their internal representation. It may therefore be the best view with which to measure the size of this representation (Cohen, Bernard, et al., 2015) and the one most able to reveal true distortions. We confirmed that, in this view, women are more likely than men to see themselves as fatter (Fallon & Rozin, 1985), but why might this be the case? Could this be due to the structure and functionality of a woman's body? We did not ask whether any of our participants had been through pregnancy, and their youthfulness suggests that that would have been rare, but the potential for pregnancy involves an explicit expectation of flexibility in this front/back dimension (Franchak & Adolph, 2014). We speculate that this flexibility and the expectation of future expansion in this dimension, not expected by men, may underlie this sex difference. Another possible explanation is that females may have acquired a general tendency to see themselves as fatter than they really are – an illusion encouraged by any amount of advertising campaigns and the media (Docteur et al., 2012; Gledhill et al., 2019; Shin & Baytar, 2013; Thompson & Mikellidou, 2011). Hashimoto & Iriki (2013) found that slightly slimmer body images were most desirable as own-body images and that this tendency is most pronounced in women (Cazzato et al., 2012).

Another study (Cornelissen et al., 2018) aimed to determine which orientation was best for body size estimation tasks responding to the lack of research on how different viewpoints affect accuracy in body mass judgements. Since the majority of research has only presented the body from the front view, it is unclear whether this is the optimal viewpoint or if important visual cues that people use for size judgments are being obscured, such as stomach depth (Rilling et al., 2009; Smith et al., 2007; Tovée et al., 1999) and thickness of the thighs and buttocks (Cohen, Bernard, et al., 2015; Cohen, Ndao, et al., 2015; Cornelissen, Gledhill, Cornelissen, & Toveé, 2016; Cornelissen et al., 2009). While their study used computer generated generic

images and did not ask for own-body size judgments, they found a loss in precision for front view stimuli compared to both three-quarter and side views (Cornelissen et al., 2018) which supports our current findings.

4.5.3. Sex and Body Satisfaction Scores

We have shown that distortions exist in both sexes for both low and high body dissatisfaction groups. Although there was surprisingly no effect of BSQ group on perceived width, there was a difference for perceived height between the males and females that were more dissatisfied with their bodies. On average across all three viewpoints, males in the high BSQ group perceived an increase in height whereas females perceived a decrease. This finding could be due to attitudinal and societal factors that are experienced by each sex. When the relationship between BSQ score and perceived size accuracy was examined, it was revealed that higher body dissatisfaction showed greater distortions in perceived width for the front and side views. This is in agreement with Mazzeurega et al. (2018) who related such findings to body attractiveness and what they called the self-serving bias. This bias is weaker in people who are less satisfied with their body and may result in greater distortions. It is difficult to compare our findings with previous studies since we used a population of healthy males and females, and therefore had a much smaller range of BSQ scores than would be seen in females with eating disorders. Another potential limitation is that our sample size was quite small for conducting correlations and that we had an unequal amount of people in the low and high BSQ groups.

4.5.4. Conclusions

Our results are important because they assess the internal representation of body dimensions independent of distortions of the body image. To extend our study and further the research done to gain knowledge about how the brain represents the body, future studies using 3D full body images/avatars should be done with our method to obtain more details about the brain's modelling and mapping of body size, shape, and structure. Other potential research that could be beneficial for comparing and contrasting with our findings (and all previous literature) would be to use our method in different experimental designs, such as testing the effects of image size, distorting both dimensions at once, distorting only particular parts of the full body, or testing a greater range of viewpoints. Findings from such lines of research could be used to develop programs to retune body representations not only in clinical populations but also for athletes and dancers where accurate body representation is particularly critical.

4.6. Ethics Statement

This study was carried out in accordance with the recommendations of the York Ethics Board. The protocol was approved by the York Ethics Board. All subjects gave written informed consent in accordance with the Declaration of Helsinki.

4.7. Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

4.8. Author Contributions

SD conceived the study and designed the experimental methodology. SD and LH devised and created the experimental methods, stimuli, and programming. SD performed the experiment and collected the data. SD analyzed the data and drafted the manuscript. Both authors contributed to the writing of the paper.

4.9. Funding

This work was supported by the Natural Sciences and Engineering Council of Canada (NSERC) grant #46271-2015 to LRH. SD was supported by a PGS-D3 NSERC graduate scholarship and an NSERC CREATE grant.

4.10. Contribution to the Field

Perceived body size is a fundamental construct that reflects our knowledge of self and is important for all aspects of perception, yet how we perceive our bodies and how the body is represented in the brain is not yet fully understood. We have developed a novel psychophysical method that taps into the implicit body representation for determining perceived size. Using this technique, we revealed distortions in perceived size for healthy, young populations and show that both viewpoint and sex matter in our brain's construction of an implicit body representation. Findings from this line of research could be used to develop programs to retune body representations not only in clinical populations where distortions may be extreme but also for athletes and dancers where accurate body representation is critical.

CHAPTER 5:

Vestibular Disruption Makes Own-Face Perception More Accurate

This chapter has been submitted to *Multisensory Research*.

5.1. Abstract

Vestibular signals are fundamental for achieving a coherent representation of the body due to the strong link that the information provides to the sense of self and awareness of one's own body. We have shown previously (D'Amour & Harris, 2017) that the internal representation of the face is perceived as wider than accurate. Here we investigated how the vestibular system might play into the representation by temporarily disrupting normal vestibular function using disruptive galvanic vestibular stimulation (dGVS) to see if the ability to perceive own face size is affected. We tested the face in three orientations to compare familiar and unfamiliar views. We found that face size accuracy and precision improved during vestibular stimulation, showing that vestibular signals contribute to and modulate the representation of the face. Faces (in an unusual orientation for high BSQ) were seen as more accurate under dGVS. These errors are reduced by dGVS suggesting that dGVS tends to remove the "special" processing given to one's own face when seen in the normal orientation, especially for people who are unsatisfied with their body.

5.2. Introduction

Visual, proprioceptive, tactile, and vestibular information are integrated to provide direct and indirect cues about body size and shape (A. Serino & Haggard, 2010). The brain maintains this representation but must plastically adjust and update it in response to changes in body shape during growth and development (Riva, 2018). The consequences of altered body representation on sensory perception have frequently been used as an indirect way of examining the nature and extent of this plasticity (e.g., Serino & Haggard, 2010). The vestibular system has been found to contribute to almost all areas of perception and of the representation of the bodily self, with strong signals and modulations occurring for touch, pain, depersonalization, body ownership, mental spatial representations, self-motion, etc., (Ferrè et al., 2012, 2015; Ferrè & Haggard, 2015, 2016; Jáuregui-Renaud, 2015; Lopez et al., 2011; Lopez, Bieri, et al., 2012; Pfeiffer et al., 2014). It is not clear yet what role vestibular signals may have on body shape and size but it is thought that disruptive GVS (dGVS) can alter the perception of the self (Hoover & Harris, 2015) and thus may at least make body size judgments less reliable. Here we directly explore the contribution of vestibular system to the perception of the size of the face.

Traditionally, the vestibular system has been neglected in the body representation literature in favour of the influence of more classic senses such as vision and touch (Ferrè & Haggard, 2016). A consequence of this is that a comprehensive multisensory model of body representation has only recently been developed (Lopez, Schreyer, et al., 2012). Primarily the vestibular system is involved in updating body position and orientation in physical space (Ferrè & Haggard, 2016; Fitzpatrick & Day, 2004; Lopez & Blanke, 2011, 2014). The vestibular system is unique among the sensory modalities in not projecting onto any single, unimodal area of the cortex specialized for its processing. Instead, the vestibular system contributes to

multisensory processes that underlie much of our perception through integration with other senses. For example, the temporo-parietal junction area of the brain receives a significant vestibular input and stimulating this area alters body representation (Lopez, Blanke, et al., 2012; Lopez, Schreyer, et al., 2012). The vestibular system thus provides a link between the sense of self and the awareness one has of one's body (Ferrè & Haggard, 2016). This is important since the body schema is constantly being updated as people move, and gravity signals received by the vestibular system during movement can assist in this process (Lopez, Schreyer, et al., 2012).

Disruption of the vestibular system has been linked to disruption of body representation. Previous studies have observed that patients with peripheral vestibular disorders often have abnormalities in perceiving the size, shape, and location of their body parts (Lopez et al., 2008; Lopez & Elzière, 2018; Yen Pik Sang, 2006). Temporary abnormalities can be introduced artificially in healthy individuals. Methods for artificial vestibular stimulation include caloric vestibular stimulation (CVS) and disruptive galvanic vestibular stimulation (dGVS). Hoover & Harris (2015) using healthy participants undergoing dGVS, created an altered sense of body ownership. One hypothesis on how the vestibular system affects body representation, suggested by Azañón et al. (2016), posits that vestibular signals modulate the weighting of the other senses, though this question still remains unresolved. Previous studies have disrupted the vestibular signal using caloric stimulation. This manipulation increased participants' perception of the length and the width of their hand (Lopez et al., 2018; Lopez, Schreyer, et al., 2012) and changed how thigh width was perceived (Schönherr & May, 2016). However, others using caloric or galvanic stimulation found no effect on perceived body size (Karnath, Kriechel, et al., 2019; Karnath, Mölbert, et al., 2019) though it has been shown to modulate perceptual, multisensory, and physiological processes that reveal how vestibular signals influence body representations

(Ferrè et al., 2011; Ferrè & Haggard, 2020; Salvato et al., 2018; Sedda et al., 2016). GVS is a more subtle, discrete and controllable way of artificially stimulating the vestibular system although the exact nature of how it works is debatable (Day et al., 2011).

The motivation of the present study was to explore how manipulating body representation affects body size perception and whether accuracy can be altered. Our psychophysical assessment method for measuring the size of the internal representation was the same as used in our previous studies (D'Amour & Harris, 2017, 2019, 2020). Vestibular signals were disrupted using vestibular stimulation to investigate the effects on perceived face size. Disruptive galvanic vestibular stimulation (dGVS) was created using an unpredictable waveform. We predicted that dGVS would cause changes in both perceived body size accuracy and precision. We tested participant's perception of their faces in three orientations – upright, right, and upside down –to see how familiar and unfamiliar views might be affected by vestibular disruption.

5.3. Methods

5.3.1. Participants

Forty participants took part in the experiment (20 females, mean age 25.33 years, SD = 10.72 years). They were recruited from the York University Undergraduate Research Participant Pool and received course credit for taking part in the study. The experiment was approved by the York Ethics Board and all participants signed informed consent forms. The study was performed in accordance with the Treaty of Helsinki.

5.3.2. Materials/Stimuli

Body dissatisfaction

The Body Shape Questionnaire (BSQ) (Cooper et al., 1987) is a 34-item self-report questionnaire that was developed to assess concerns about body shape and experiences of feeling fat that participants may have experienced within the previous month. Each question uses a scale from 1 (never) to 6 (always) that are added together to obtain a total BSQ score ranging from 34 – 204, with lower scores indicating lower levels of body dissatisfaction and higher scores indicating higher levels of body dissatisfaction. The test was administered before the experiment began to obtain a measure of body dissatisfaction. The total BSQ score was used for correlations. To create categorical groups, participants were divided into high and low groups according to whether their score was above or below the overall mean.

Photographs

Color photographs of each participant were taken using a digital camera (Canon EOS Rebel T6). Participants were asked to stand in front of a wall with a neutral facial expression. Photographs were taken under standardized conditions with the flash on, from just above the head to the waist, from a distance of approximately four feet (122 cm) with no zoom function. The image was then corrected for any lens distortions, cropped and flipped to include only the participant's head in mirror perspective, and formatted with a white background (Adobe Photoshop CC 2017). This image served as the undistorted "real" image and was used for composing the distorted images. Using a soft tape measure, face size was measured straight down from the top of the forehead to the bottom of the chin. The image was then adjusted to life-size by adjusting the magnification of the image until it matched the participant's actual face size.

Distorting the images

Images were presented and distorted through the use of MATLAB (version 2015b) and Psychophysics Toolbox (Brainard, 1997) running on a MacBook Pro. One dimension of the image (either width or length) was distorted (made either bigger or smaller) using a QUEST adaptive staircase psychometric procedure (Watson & Pelli, 1983). The monitor was viewed orthogonally to the line of sight with the viewer aligned with in the center of the photograph. The image was displayed on the center of a computer monitor (27-inch Apple display) with the face in one of the three orientations: (1) upright (0°), (2) to the right (90°), and (3) upside down (180°). Width and length dimensions were distorted separately for each of the three orientations, resulting in six conditions.

Galvanic Vestibular Stimulation

We used disruptive galvanic vestibular stimulation (dGVS) to non-invasively stimulate the vestibular system (Hoover & Harris, 2015). The experimental setup is shown in Figure 5.1. Two round electrodes (diameter 1.25 inches) coated with electrode gel were positioned on the mastoid processes behind the ears and one reference electrode was placed on the centre of the forehead. The electrodes were placed at the beginning of the session and were kept fixed in place with adhesive tape. Vestibular stimuli were delivered by a GVS system (Good Vibrations Engineering Ltd., Nobleton, ON, Canada) programmed to generate an unpredictable sum-of-sines waveform with frequencies at 0.16, 0.32, 0.43, and 0.61 Hz (maximum current limited to ± 2.5 mA) (Hoover & Harris, 2015).

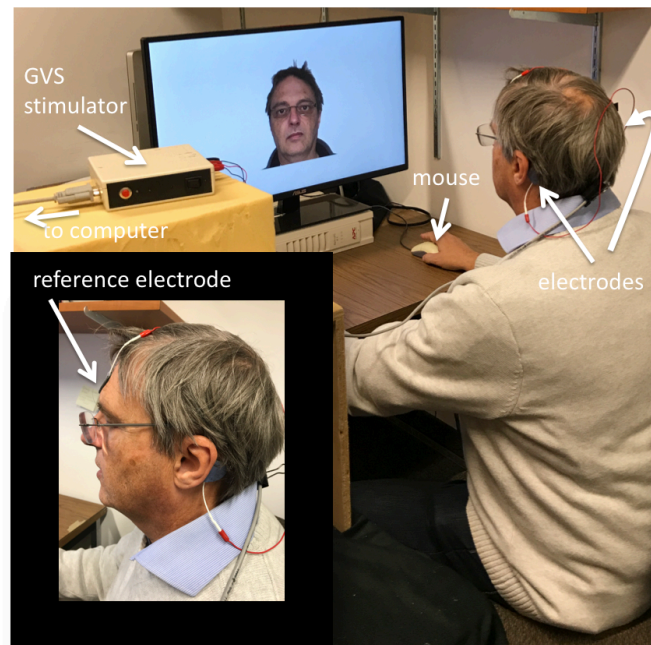


Figure 5.1. Vestibular disruption experimental setup

5.3.3. Procedure

Participants sat in a chair approximately 45 cm in front of the computer screen. Each trial consisted of two 1.5s intervals – one interval containing the undistorted image and one interval containing the distorted image - separated by a blank white screen. Participants identified which interval contained the image that most closely matched their own perception of their face and responded using a two-button computer mouse (left button for first interval, right button for second interval). A QUEST adaptive staircase procedure (Watson & Pelli, 1983) was used with a two-alternative forced choice (2AFC) design to vary the chosen dimension (length or width) of the distorted image. Two QUEST staircases (25 trials per staircase) were used for each condition (50 trials total), with one starting with the manipulated dimension larger than natural and the other starting with that dimension smaller than natural. Data for every condition (orientations; dimensions) was collected both with and without stimulation in order to determine if accuracy values change during the presence of dGVS (resulting in a total of 12 conditions. The experiment was run in a block design where stimulation was applied in six-minute blocks interleaved with six-minute blocks of no stimulation. Block order was determined by a Latin square and was counterbalanced across participants.

5.3.4. Data Analysis

The QUEST program returned an estimate of the distortion needed for the participant to report that the distorted image was equally like their perceived face size as the undistorted image. The algorithm assumes the observer's psychometric function follows a Weibull distribution and adaptively determines the amount of distortion to be presented based on the participant's response to the previous trials. As the experiment goes on, knowledge on the observer's

psychometric accumulates. To visualize and confirm the QUESTs performance, the participant's decision was plotted against the distortion used for each trial and fitted with a logistic (Equation 5.1) using the curve fitting toolbox in MATLAB.

$$\text{Decision} = 1/(1+\exp(-(x-x_0)/b)) \dots\dots\dots (5.1).$$

where x_0 is the actual size, x is the distorted value that was equally likely to be judged as matching the observer's face size, and b is an estimate of the slope of the function. The size of the internal body representation was taken as the point halfway between x (the size judged as equally like their face as x_0) and x_0 (the undistorted image size), as seen in Equation 5.2.

$$\text{Representation size} = (x - x_0)/2 \dots\dots\dots (5.2)$$

All of the 40 participants' data for each condition were examined to validate the accuracy and efficiency of the QUEST procedure. The QUESTs performance was also checked to determine whether reliable estimates were obtained within 50 trials. All data were inspected for outliers defined as points that fell outside ± 3 standard deviations from the mean. Data that failed to meet these criteria were discarded from the analyses (5 participants – 3 males, 2 females). Estimates were converted to percentages relative to the accurate reference photograph ($\text{rep} \times 100 / x_0$) and data analyses were conducted on these values. Correlations and mixed measures analyses of variances (ANOVAs) were used for statistical analyses, with alpha set at $p < .05$ and post-hoc multiple comparisons were made using Bonferroni corrections.

5.4. Results

5.4.1. Face Size Accuracy: Width and Length Dimensions

Two separate four-way mixed measures ANOVAs were conducted on orientation (upright, right, upside down), vestibular condition (control, GVS), sex (male, female), and BSQ Group (low, high) for each dimension: Width – a significant three-way interaction between orientation, vestibular condition, and BSQ group, $F(2, 62) = 3.35$, $p = .041$, $\eta_p^2 = .098$, power = .613; Length - a significant four-way interaction was found between orientation, vestibular condition, sex, and BSQ group, $F(2, 62) = 3.25$, $p = .045$, $\eta_p^2 = .095$, power = .599).

Figure 5.2 shows the difference from accurate for perceived face width and length with the face viewed in the three orientations. Data for males and females, and for low and high BSQ groups are plotted separately to show the effects from breaking down the interactions. Accuracy was improved for the right and upside-down orientations when GVS was applied for both width and length judgements. The high BSQ group had improvements for face size perception during dGVS when the face was presented in unusual orientations.

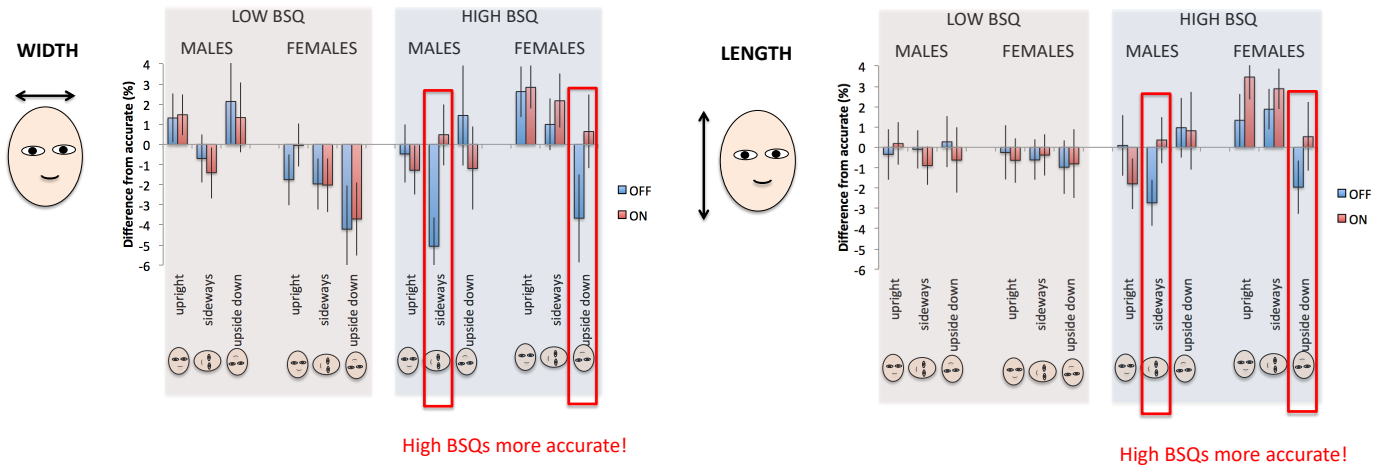


Figure 5.2. Difference from accurate (%) for males and females in the low (brown panels) and high (blue panels) BSQ groups with (red bars) and without (blue bars) disruptive galvanic vestibular stimulation (dGVS). The left panel shows the results for width and the right shows results for length. Standard errors are shown. The red rectangles indicate the conditions for which dGVS caused a significant change.

5.4.2. Precision of the Judgements

The slope of the functions was measured from the curve fits (see methods) to assess whether precision was changed by vestibular stimulation. A three-way repeated measures ANOVA was conducted on orientation (upright, right, upside down), dimension (width, length), and vestibular condition (control, GVS). It revealed significant main effects for Orientation, $F(2, 68) = 3.73$, $p = .029$, $\eta_p^2 = .099$, power = .665, and Vestibular, $F(1, 34) = 4.27$, $p = .046$, $\eta_p^2 = .112$, power = .519. The slope decreased when GVS was applied, indicating an improvement in precision during vestibular stimulation (see Figure 5.3).

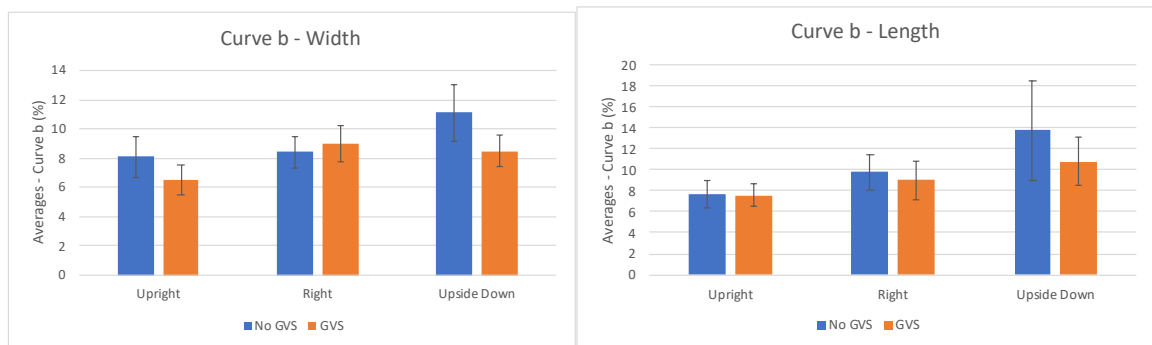


Figure 5.3. Slope values for each orientation are shown for width (left panel) and length (right length).

5.5. Discussion

We have shown that the vestibular sensory system impacts body size perception and that vestibular input seems to be involved in how we perceive and represent our face size. The results found that face size accuracy and precision improved during vestibular stimulation, showing that vestibular signals contribute to and modulate body representation. The face seen in an unusual orientation for high BSQ were seen as more accurate under GVS. In our previous work (D'Amour & Harris, 2017), we showed that faces viewed upside down had the biggest errors, especially for people with high BSQ scores. We now show that these errors seem to be reduced by dGVS suggesting that dGVS tends to remove the “special” processing given to one’s own face when seen in the normal orientation, especially for people who are unsatisfied with their body. Longer exposure to dGVS could be useful in helping people come to terms with their own body.

5.5.1. Why is Perceived Face Size Affected by its Orientation?

Why might face size be misperceived when tilted or inverted? Presumably an internal rotation of the representation is required to compare with the presented image since faces, even our own in the mirror, are usually perceived upright. Such transformations take time and the rotation of body parts appear to be similar to the mental rotation of any objects (Petit et al., 2003). Vestibular stimulation has been shown to disrupt mental rotation tasks (Falconer & Mast, 2012; Lopez et al., 2011; Mast et al., 2006; Mast & Ellis, 2015) reflecting the mutually inhibitory connections between visual and vestibular cortical areas (Brandt, 1998). We postulate that the vestibular input involved in the internal mental rotation required to do our task not only is involved in the rotation itself but is also determines the nature of the representation being rotated.

5.5.2. The Effect of Sex and BSQ on Own-Face Perception

Given the lack of research on the processes by which the vestibular system affects body size perception, it is unclear why dGVS resulted in significantly more accurate performance only for those with high body dissatisfaction. Cash & Deagle (1997) found that patients with eating disorders had body size distortions but not generalized perceptual deficits, since they provided similar size judgements of neutral objects as control participants. As such, it appears unlikely that those with high body dissatisfaction performed differently due to a generalized perceptual deficit. One possible explanation is that this demographic is more susceptible to change when stimulated with dGVS, since vestibular signals have been shown to influence the neural basis of the body schema (Rode et al., 2012).

5.5.3. The Effect of Galvanic Stimulation

Like much of the literature on the consequences of vestibular stimulation, this study found some evidence that dGVS can affect body representation, though previous results are mixed with regards to body size perception. For example, we support the observation by Lopez et al. (2008; 2012) that perceived hand size is altered by caloric vestibular stimulation. However, we contradict the findings of Ferrè et al. (2013), who found that vestibular stimulation did not affect perceived hand size. This divergence in findings may be due to a number of differences between the present study and the cited studies, namely that the present study tested perceived face size only and only galvanic stimulation was used. Also, Ferrè et al. (2013) primarily investigated the ability to localize touch, where participants were required to point to the perceived location of their hands. This reflects a body part size perception task that tests a

different sensory modality, since the present study tests participants' internal representation of their body size using a visual method. Due to the difference in results between the present study and Ferrè et al. (2013), it can be speculated that the way in which the vestibular system interacts with the somatosensory system compared to the visual system may differ.

5.5.4. Why Might Vestibular Disruption Improve Face Size Perception?

Our results imply that somehow the vestibular system is actually altering the perception of our own faces and removing errors, especially in people with high BSQs. This may give us an insight into the ephemeral connection between the body representation and the body schema. The body schema is known to be influenced by cognitive factors (Dijkerman & Lenggenhager, 2018). It would seem that this connection involves a vestibular component. When this is disrupted, the brain is forced to rely on a more basic representation – perhaps more sensorily than cognitively based – which may bypass the distortions imposed on a person's emotionally influenced perception of their own body. This gives hope to people with seriously distorted own-body perceptions as a potential way of removing these cognitive influences – at least temporarily. By understanding how the internal representation of the body is distorted and can be manipulated, we can improve our understanding of the plasticity and flexibility of the brain, as well as how it can accommodate and recover from sensory manipulations (both through natural development or by laboratory manipulations). This potentially allows us to use this information in situations where it is desirable to introduce a change in perceived body size.

5.5.5. Conclusions

We have shown that the vestibular sensory system impacts body size perception and that vestibular input seems to be involved in how we perceive and represent our bodies. Accuracy and stability of body representation are flexible and can be changed dynamically. Susceptibility of the representation of the body to change after such brief experience suggests body representation may be even more plastic than previously thought.

CHAPTER 6:

Measuring Perceived Full Body Size Accuracy After Adaptation to Distorted Visual Exposure

This chapter is being written up for publication in Body Image.

6.1. Abstract

Perceptual biases of body size are influenced by different environmental stimuli and by experience. Inaccurate perceptions, like under- or over- estimations of body size, are often found in clinical eating disorder populations, but have recently been shown in healthy people as well. However, it is not yet clear how body size perception may be affected when body representation is manipulated. In this study, visual adaptation was used to investigate if exposure to distorted visual feedback could alter perceived body size accuracy and for how long these effects last. Participants were exposed for five minutes to a distorted image of themselves that was either 20% wider or 20% thinner than their normal size. Accuracy was measured using our novel psychophysical method that taps into the implicit body representation. Following exposure to adaptation, perceived size accuracy was assessed three times at 6, 12, and 18 minutes to obtain a time course for any effects. Altered visual feedback caused changes in perceived body size. Adapting to a bigger body resulted in size overestimation whereas underestimations occurred after adapting to a smaller body. These distortions also lasted throughout testing and did not fully return back to normal. The results reveal how body size perception and representation can be dynamic and flexible.

6.2. Introduction

Perceptual biases of body size are influenced by different environmental stimuli and by experience. However, it is important that the brain accurately represents the body because of how essential it is to our everyday life. Inaccurate perceptions like underestimation or overestimation of the whole body can occur due to perceptual disturbances, such as those found in eating disorder populations (McCabe et al., 2006). As well, perceptual disturbances of the body image also occur in healthy people and not just clinical populations (e.g. D'Amour & Harris, 2017, 2019, 2020). Therefore, it is also crucial to understand the underlying mechanism that causes this inaccuracy to occur in the non-clinical population. Knowing how the body is represented in the brain is critical to understand proprioception and motor functioning (Fontan et al., 2017).

There are two important processes that impact the perception of body image (McCabe et al., 2006). First, the integration of various sensory inputs such as tactile, kinesthetic, and visual cues to body size. Secondly, there are non-sensory factors including cognitive factors based on prior knowledge of the body or on individual beliefs. This study investigates the former – if visual feedback contributes to the perception of body size (for example by looking in a mirror), can distorting this feedback influence perceived body size?

6.2.1. Visually Modifying Perceived Body Size

Visually modifying the perceived size of the body, for example by viewing the body through a magnifying lens, is known to impact tactile perception (Kennett et al., 2001), tactile distance perception (Taylor-Clarke et al., 2004), tactile size perception (Longo & Sadibolova, 2013), haptic perception (Bruno & Bertamini, 2010), pain perception (Mancini, Longo, Kammers, et al., 2011; Moseley et al., 2008), the perceived size of objects and their perceived

distance from the observer (van der Hoort et al., 2011), the rubber hand illusion (Pavani & Zampini, 2007), and motor control, such as grasping (Bernardi et al., 2013; Marino et al., 2010). These observations all suggest that visually changing perceived body size can indeed alter a person's mental representation of their body and that these changes can affect perception. Distorting perceived body size and shape visually (Bruno & Bertamini, 2010; Marino et al., 2010; Moseley et al., 2008; Taylor-Clarke et al., 2004; Walk & Heller, 2014), proprioceptively (D'Amour et al., 2015; de Vignemont et al., 2005; Ehrsson et al., 2005; Lackner, 1988; Longo et al., 2009) or with cutaneous anaesthesia (Gandevia & Phegan, 1999) provides further evidence of the complex relationship between sensory perceptions and the body representation to which it is referenced. However, none of these studies has used natural sized images of the participant themselves and therefore we set out to use visual adaptation using such personalized natural images.

6.2.2. Visual Adaptation

There has been extensive amount of research looking at the effects of adaptation in multiple different areas of study. Even within the realm of body perception, research is wide ranging and varied (see review by Challinor et al., 2017). For example Ambroziak et al. (2019) used avatar images on a small computer screen and Stephen et al. (2016, 2018, 2019) uses photographs that have the face hidden with a black square. Most studies use other people for their participants to adapt to in order to investigate the influence of various cultural factor such as race (Gould-Fensom et al., 2019), media and society (Sturman et al., 2017; Thornborrow et al., 2020), and gender (Brooks et al., 2019) to investigate how much these environmental factors might influence body perception.

But these and other studies have all shown how visual adaptation can alter the visual perception of the participant's own body (Hummel, Rudolf, et al., 2012). The effects of such visual adaptation is known to be a brief change that occurs in perception or sensitivity following exposure to a specific stimulus (Webster, 2015). Even a brief exposure to a distorted body image has an impact on perceived body size accuracy and causes individuals to over- or under-estimate their own size (Glauert et al., 2009; Hummel et al., 2012; Urdapilleta et al., 2010). Generally, after participants are adapted to a thinner picture of themselves, this led the participants to judge their perceived body size to also be thinner. How much of this is a simple visual after effect, comparable to low-level adaptation such as after staring at a low-spatial frequency grating (e.g., Blakemore et al., 1970) and how much might be due to central effects on the actual brain representation? In order to assess this, we used the novel psychophysical method described in our previous studies (D'Amour & Harris, 2017, 2019, 2020). This method, since it does not involve participants ever actually seeing the image-size that they judge as their own, gives us a direct estimate of their body representation.

Using our psychophysical method, participants were first run with no manipulation to obtain baseline accuracy values. They were then exposed to five minutes of a distorted image of their own full-sized body that was either 20% wider or 20% narrower than their actual size. We expected that altering visual feedback would cause changes in perceived body size, with accuracy values following the direction of adaptation – adapting to a bigger body would result in size overestimations whereas underestimations would occur when adapted to a smaller body. Following adaptation, perceived size accuracy was assessed three times at 6, 12, and 18 minutes

to obtain a time course for any effects. We hypothesized that visual adaptation, even with a brief period of exposure, would impact accuracy and stability of body representation. These changes would be present in the time course assessments, with decay occurring in each test session. We also expected that there would be differences between the adaptation directions – with the prediction that adapting to a bigger body would be more effective and have greater changes in accuracy.

6.3. Methods

6.3.1. Participants

Thirty participants took part in the experiment (17 females, mean age 24.1 years, SD = 7.91 years). They were recruited from the York University Undergraduate Research Participant Pool and received course credit for taking part in the study. The experiment was approved by the York Ethics Board and all participants signed informed consent forms. The study was performed in accordance with the Treaty of Helsinki.

6.3.2. Materials/Stimuli

Body dissatisfaction

The Body Shape Questionnaire (BSQ) (Cooper et al., 1987), is a 34-item self-report questionnaire that was developed to assess concerns about body shape and experiences of feeling fat that participants may have experienced within the previous month. Each question uses a scale from 1 (never) to 6 (always) that are added together to obtain a total BSQ score ranging from 34 – 204, with lower scores indicating lower levels of body dissatisfaction and higher scores indicating higher levels of body dissatisfaction. The test was administered before the experiment

began to obtain a measure of body dissatisfaction. The total BSQ score was used for correlations. To create categorical groups, participants were divided into high and low groups according to whether their score was above or below the overall median.

Photographs

Color photographs of each participant's whole body were taken using a digital camera (Canon EOS Rebel T6; flash on; no zoom function), with a camera distance of 270 cm. Participants were asked to stand in front of a white wall, wearing a standardized black outfit that was provided to obtain accurate outlines of their size and shape. The images were then corrected for any lens distortions, cropped to include only the whole body, and formatted on a white background (Adobe Photoshop CC 2017). The image served as the undistorted reference images and was used for composing distorted images. Actual body height was measured from the bottom of the feet to the top of the head using a ruler taped up to a wall. The image was presented life-size projected (using a BenQ 1080p short throw projector) onto a screen at a viewing distance of 270 cm by digitally adjusting the magnification of the image until it physically matched the participant's actual body size. The viewing distance was chosen as matching the camera's focal length multiplied by the magnification (Cooper et al., 2012) which minimizes distortions.

Distorting the images

Images were presented and distorted through the use of MATLAB (version 2011b) and Psychophysics Toolbox (Brainard, 1997) running on a MacBook Pro. The width dimension of the image was distorted (made either bigger or smaller) using a QUEST adaptive staircase

psychometric procedure (Watson & Pelli, 1983). The image was viewed in the center of a projector screen with the full body shown from the front view.

Altering visual feedback with images

The experimental setup is shown in Figure 6.1. Participants first assessed the perceived size of the full body to obtain baseline accuracy values with no manipulation. Adaptation stimuli was created by altering the width of the image by 20% larger or smaller (see Figure 6.2). Both manipulations were tested for each participant but were done on separate days. Participants viewed this distorted image for 5 minutes. They were then assessed multiple times without top ups. The assessment method takes 6 minutes so they were tested 6, 12, and 18 minutes after adaptation to look for the decay of any effect. Only one adapting regime (e.g., body widening) was used in any one testing session (see Figure 6.3).

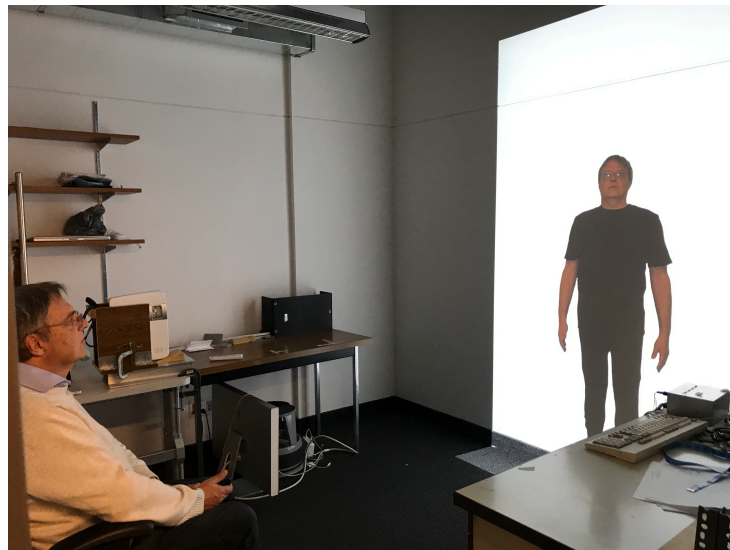


Figure 6.1. Visual adaptation experimental setup.



Figure 6.2. Example of altered visual feedback stimuli. Participants were exposed for five minutes of a distorted image of their body that was either 20% wider or 20% narrower than regular.

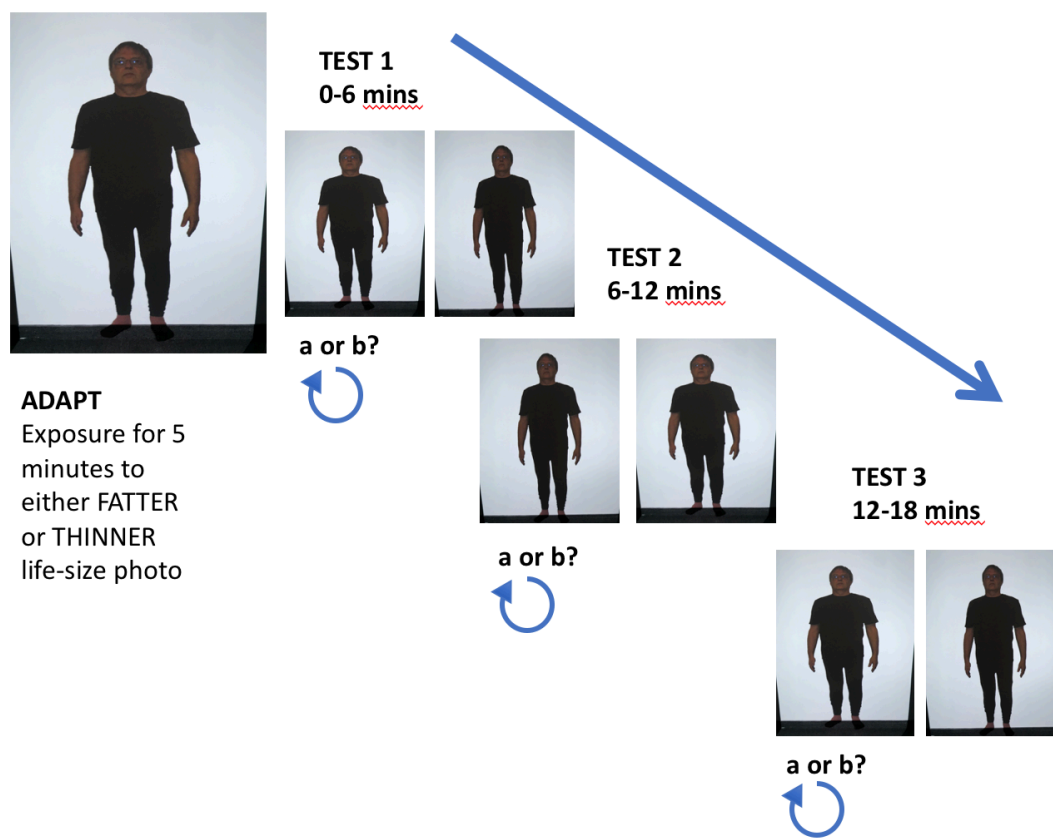


Figure 6.3. Visual adaptation experimental design. Following the five minutes of adaptation, perceived size accuracy was assessed three times to obtain measures at 6 minutes, 12 minutes, and 18 minutes to get a time course for any adaptation effects

6.3.3. Procedure

Participants sat in a chair approximately 270 cm from the projector screen. Each trial consisted of two 1.5s intervals – one interval containing the undistorted image and one interval containing the distorted image - separated by a blank white screen. Participants identified which interval contained the image that most closely matched their own perception of their body and responded using a two-button computer mouse (left button for first interval, right button for second interval). A QUEST adaptive staircase procedure (Watson & Pelli, 1983) was used with a two-alternative forced choice (2AFC) design to vary the width of the distorted image. Two QUEST staircases (25 trials per staircase) were used for each condition (50 trials total), with one starting with the manipulated dimension larger than natural and the other starting with that dimension smaller than natural.

They were then shown a distorted image of themselves for 5 mins and asked to scan around the picture. After this, the above procedure was repeated three times (see Figure 6.3). As the procedure took about 6 minutes, this allowed us to assess perceived body size at 6, 12 and 18 minutes after exposure to the adapting stimulus.

6.3.4. Data Analysis

The QUEST program returned an estimate of the distortion needed for the participant to report that the distorted image was equally like their perceived body size as the undistorted image. The algorithm assumes the observer's psychometric function follows a Weibull distribution and adaptively determines the amount of distortion to be presented based on the participant's response to the previous trials. As the experiment goes on, knowledge on the observer's psychometric accumulates. To visualize and confirm the QUESTs performance, the

participant's decision (0 for smaller, 1 for bigger) was plotted against the distortion used for each trial and fitted with a logistic (Equation 6.1) using the curve fitting toolbox in MATLAB.

$$\text{Decision} = 1/(1+\exp(-(x-x_0)/b)) \dots\dots\dots (6.1)$$

where x_0 is the undistorted size, x is the distorted size that was equally likely to be judged as matching the observer's body size, and b is an estimate of the slope of the function. The size of the internal body representation was taken as the point halfway between x and x_0 . We then subtracted x_0 from this value to derive a difference-from-accurate score where positive numbers corresponded to an overestimate and negative numbers to an underestimate.

All of the 30 participants' data for each condition were examined to validate the accuracy and efficiency of the QUEST procedure. The QUESTs performance was also checked to determine whether reliable estimates were obtained within 50 trials. All data were inspected for outliers. Outliers were defined as points that fell outside ± 3 standard deviations from the mean. All the data from a participant that failed to meet these criteria were discarded from the analyses (1 participant – 1 male).

Baseline accuracy values from the control condition were subtracted from the adaptation values for each condition to obtain change score values that were used for data analyses. One-sample t tests were conducted for each condition to assess whether difference-from-accurate values significantly differed from zero (accurate). Mixed measures analyses of variances (ANOVAs) were used for statistical analyses, with alpha set at $p < .05$ and post-hoc multiple comparisons were made using Bonferroni corrections.

6.4. Results

Figure 6.4 shows the results for perceived body width after adaptation to a bigger and smaller body. One-sample t tests were conducted to see if the adaptation values were different from accurate at the different time points. Adapt big was significantly different from their pre-test scores for all three test sessions (all p 's $< .05$). Adapt small was significantly different for the first test session ($p = .001$), trending for the second ($p = .082$), and showed no difference by the third ($p = .128$).

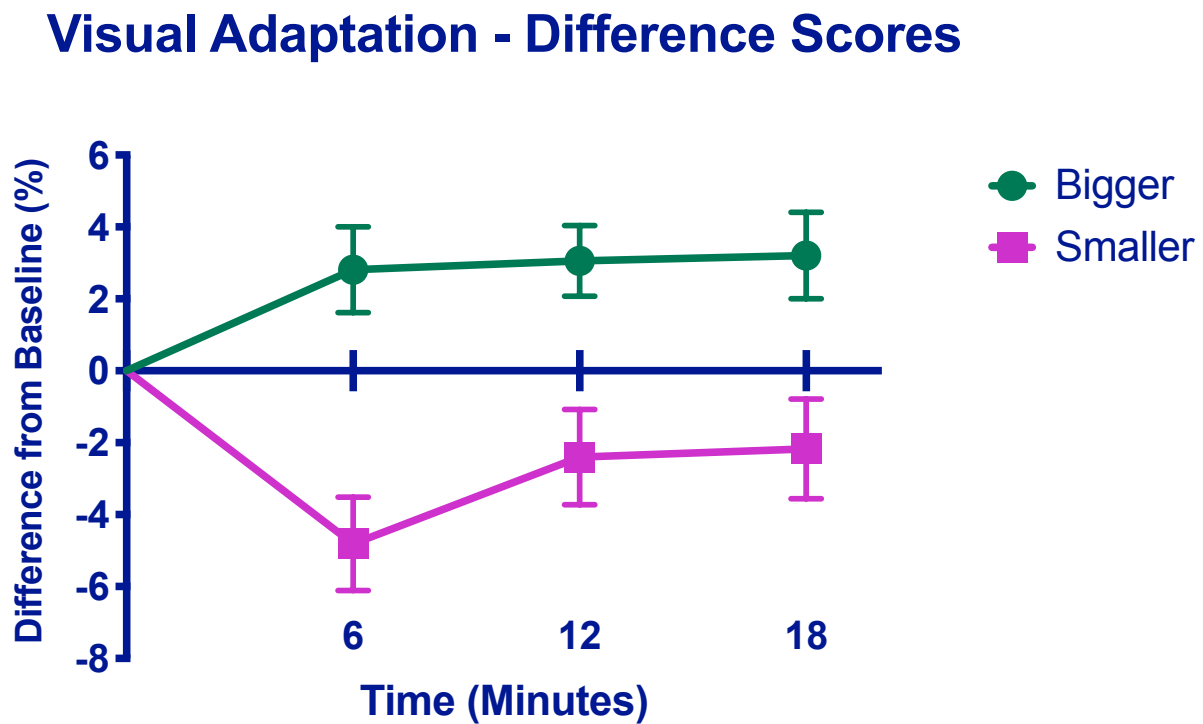


Figure 6.4. Visual adaptation results. Scores are percentage changes relative to their control levels measured immediately before adaptation.

A four-way mixed ANOVA was conducted to test for the within-subjects effects of altered visual feedback type (bigger or smaller), time (6, 12, or 18 minutes), and the between-subjects effects of sex (male and female) and BSQ group (low and high). There was a significant effect found for type, $F(1, 25) = 17.47$, $p < .001$, $\eta^2 = .411$, and for time, $F(2, 50) = 3.90$, $p = .027$, $\eta^2 = .135$. A significant interaction was also observed between type and time, $F(2, 50) = 5.02$, $p = .011$, $\eta^2 = .167$. There was a significant four-way interaction between type, time, sex, and BSQ group, $F(2, 50) = 4.15$, $p = .022$, $\eta^2 = .142$. Figure 6.5 shows the interaction broken down by the factor levels and groups.

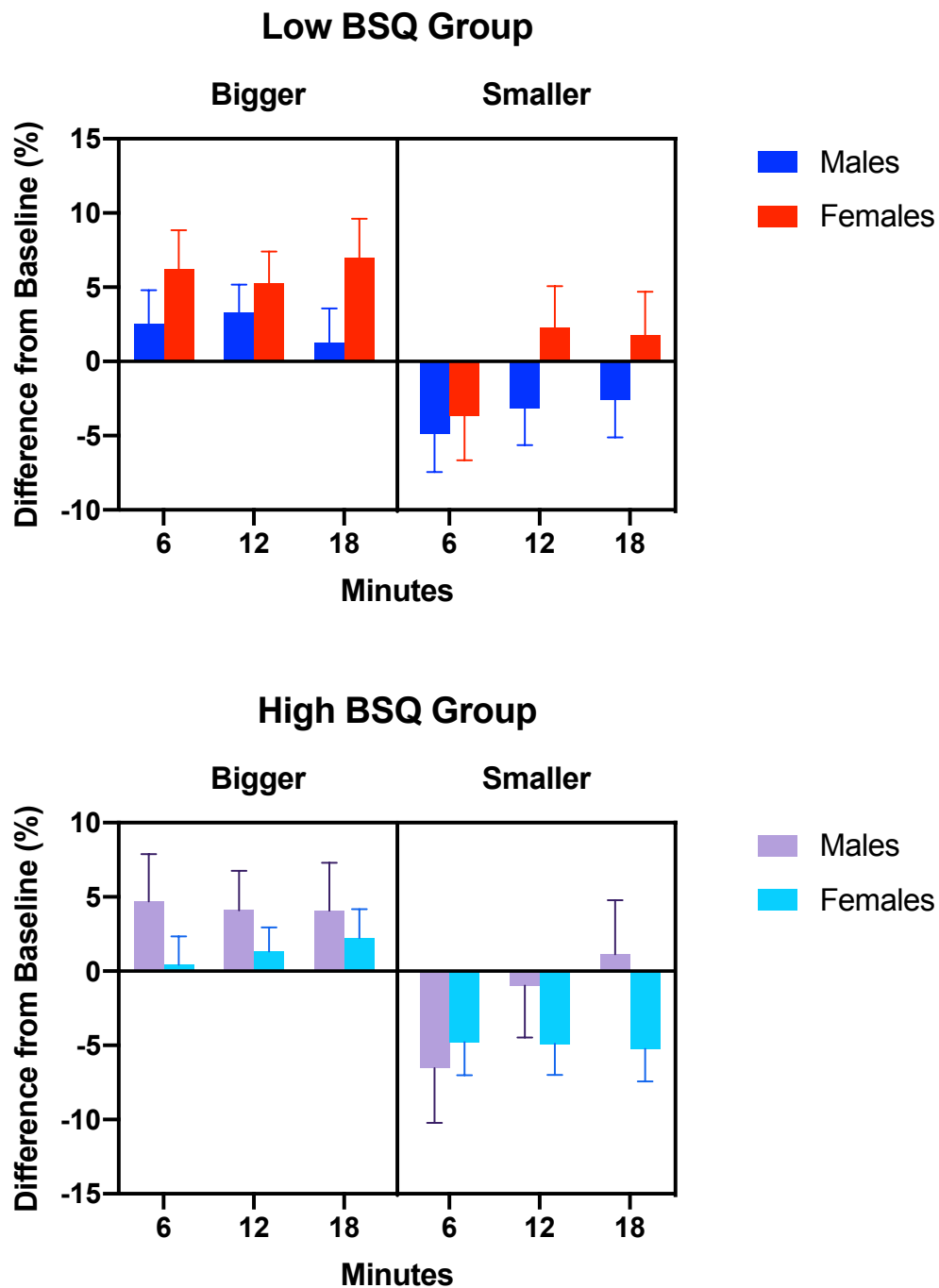


Figure 6.5. Visual adaptation results broken down by all factors. The graph shows the effect of adaptation after adapting bigger (left) and smaller (right) for males (blue and purple) and females (red and pale blue) for the low BSQ group (top) and high BSQ group (bottom).

6.5. Discussion

This research investigated how exposure to distorted visual images of one's own natural-sized body impacted perceived body size. These findings showed that exposure to distorted full size images indeed caused changes in perceived body size. After adapting to the wider body, there was a lasting effect in which people perceived their own body to be wider. After adapting to the narrow body, people thought that they were smaller than they actually were. These distortions did not return back to normal by the end of the testing sessions (18 mins). These findings clearly answer the question of whether visually manipulating body representation can alter accuracy values and provides insight into how people perceive their body size.

We interpret these effects as altering the body representation as opposed to being a simple perceptual effect that resulted from fatiguing particular units or channels. Firstly, such effects are short lived as they depend on depleting the resources of a particular set of cells in the brain that are quickly restored once the adapting stimulus is removed (Blakemore et al., 1970). Secondly, the misbalance resulting from such adaptation produces a negative after effect in which subsequent visual stimuli are perceived as shifted in the opposite direction to the adapting stimulus. For example, after looking at a low spatial frequency, a test grating is perceived as having a higher spatial frequency (Blakemore et al., 1970). Thirdly, we found varying effects related to the different factors and groups considered in this study. If our adaptation effects were due only to low-level visual perception adaptation mechanisms then everyone should be similar and show comparable levels of adaptation.

Though we found differences between the variables and groups we tested, everyone experienced changes in perceived size after adaptation in the positive direction (the same direction as the viewed distortion). Although distortions were found after adaptation independent of sex or body dissatisfaction, there were differences between the groups (see Figure 6.5). Surprisingly perhaps, greater distortions occurred in general for males although large effects were also seen for females in the low BSQ group when adapting bigger, and for females in the high BSQ group when adapting smaller. It has been shown that adaptation to fat body images is reduced for females with higher body dissatisfaction (Glauert et al., 2009; Mohr et al., 2016). This could be related to the distortions commonly found in clinical disorders (Cornelissen et al., 2015; Gardner & Boice, 2004) or perhaps the differences in average body size between males and females (Brooks et al., 2016; Cornelissen, Gledhill, Cornelissen, & Tovée, 2016; Harris et al., 2008)

A recent review by Brooks et al. (2020) covered several key points surrounding adaptation in body size research and provided support for high-level adaption of body representation. For example, Hummel, Grabhorn, and Mohr (2012) showed that adaptation aftereffects to wide bodies affected the subsequent perception of participant's own body but adaptation to wide and narrow black rectangles caused no such perceptual distortion for subsequently viewed bodies. Such observations support the idea of adaptation to images of distorted bodies causing their effects at a high level specific to body shape, and not just a low-level effect of width in general. Furthermore, adaptation effects are maintained despite changes in body orientation (Brooks et al., 2018). Thus, for these reasons and with the support of studies such as those reviewed by

Brookes et al. (2020), we conclude that our adaptation effects operated directly at the level of the body representation in the brain.

The main focus of this study was to look at the extent and timing of the adaptation exposure. Future studies should explore the areas we have looked at in previous studies (different body parts, viewpoints and orientations, and length dimension) to consider questions such as: 1) Are those body parts that have greater baseline distortions more flexible to manipulations? 2) Are viewpoints that are more and less familiar impacted differently with manipulations? Does viewpoint familiarity matter? Do we adapt more or less when it is a view we are used to? 3) Does adaptation transfer to different viewpoints? Is adaptation to one's own self specific to the same self-view or is adaptation of one's self more general? It would also be interesting to use my experimental paradigm to compare adaptation to the self, with the effects of adapting to other people (including opposite sex), and objects.

CHAPTER 7:
General Discussion

This dissertation has investigated the accuracy and stability of body representation by exploring two main themes – 1) Measuring Perceived Size, where my experiments looked at how accurate we are at estimating our actual real body size compared to distorted images, and 2) Assessing the Plasticity of the Body Representation, where sensory manipulations were used to try and alter body size accuracy and if so, by what extent and for how long. The overall aim of this research was to provide a comprehensive understanding of how the body is perceived and represented in the brain. To do this, I considered the issues and limitations from the wide-ranging areas of research that have previously looked at the body and then created a novel experimental method for determining perceived body size that provided an objective, unbiased, implicit measure of the size of body representation in the brain. Several research questions were investigated in each experiment. Overall, I have assessed and manipulated perceived body size accuracy while considering or varying several different factors and shown the critical roles that body part, viewpoint, orientation, sensory systems, sex, and body satisfaction play in body size perception and body size accuracy. These experiments extend our knowledge of how the brain represents the body and demonstrate that the accuracy and stability of body representation are flexible and can be changed dynamically.

7.1. Summary of Major Findings

7.1.1. Theme 1 Experiments - Measuring Perceived Size

For the first theme of my research, perceived body size was measured in healthy populations of both males and females to determine how accurate people are at judging their body size and to obtain baseline values of how distorted the brain's representation of various body parts are. Chapter 2 investigated perceived face size in eight conditions. Either the width or

length of the face was distorted, and accuracy was measured when the face was presented in four different orientations. This experiment found that the face was perceived as wider and shorter in the upright and upside-down orientations, with greater distortions occurring for females compared to males and those with higher levels of body dissatisfaction compared to those with lower levels. These results demonstrate that viewpoint, body satisfaction, and sex matter for the accuracy of face size perception. Chapter 3 assessed hand and palm perceived size with 16 conditions, where either the width or length was distorted, and accuracy was measured with the hand in four orientations. The main findings were that perceived hand width differed depending on whether it was seen upright or sideways, and the back of the hand was perceived as longer than actual size while palm size was perceived accurately. Here, perceived size was found to be impacted by viewpoint and body part. Chapter 4 looked at full body size perception in six conditions. Photographs of the participant's full body were presented as seen from three different viewpoints with either the width or length distorted. The results of this experiment revealed that the full body was perceived as thinner in front and back view, overestimation of the width of the side view occurred for females, but the height of the body was perceived as accurate. These findings show that viewpoint and sex matter for full body size perceptual accuracy.

7.1.2. Theme 2 Experiments – Assessing the Plasticity of the Body Representation

For the second theme of my research, the perception of the body was manipulated and altered in order to investigate how flexible our body representation is. This was done by testing to see whether body size detection accuracy was changed when body perception was distorted, disrupted, and modulated using two separate methods that altered vestibular or visual sensory information. Chapter 5 used disruptive galvanic vestibular stimulation to disrupt the stabilizing

of the body schema to see if the face size perception was affected. This experiment found that vestibular stimulation had an effect on face size perception, with faces in an unusual orientation being seen as more accurate under GVS for people with higher levels of body dissatisfaction. The findings reveal that vestibular signals contribute to and modulate body representation, and that vestibular input seems to be involved in how we perceive and represent our bodies. Chapter 6 used visual adaptation to see if exposure to distorted visual feedback could alter perceived full body size accuracy and for how long. Exposing people to five minutes of a distorted image that was 20% wider or 20% narrower than their regular size resulted in changes to perceived body size accuracy. After adapting to the wider body, there was a lasting effect in which people perceived their own body to be wider. After adapting to the narrow body, people thought they were smaller than they actually were. These distortions did not return back to normal by the end of the testing sessions. These findings suggest body representation may be even more plastic than previously thought due to the susceptibility of the representation of the body to change after such brief experience.

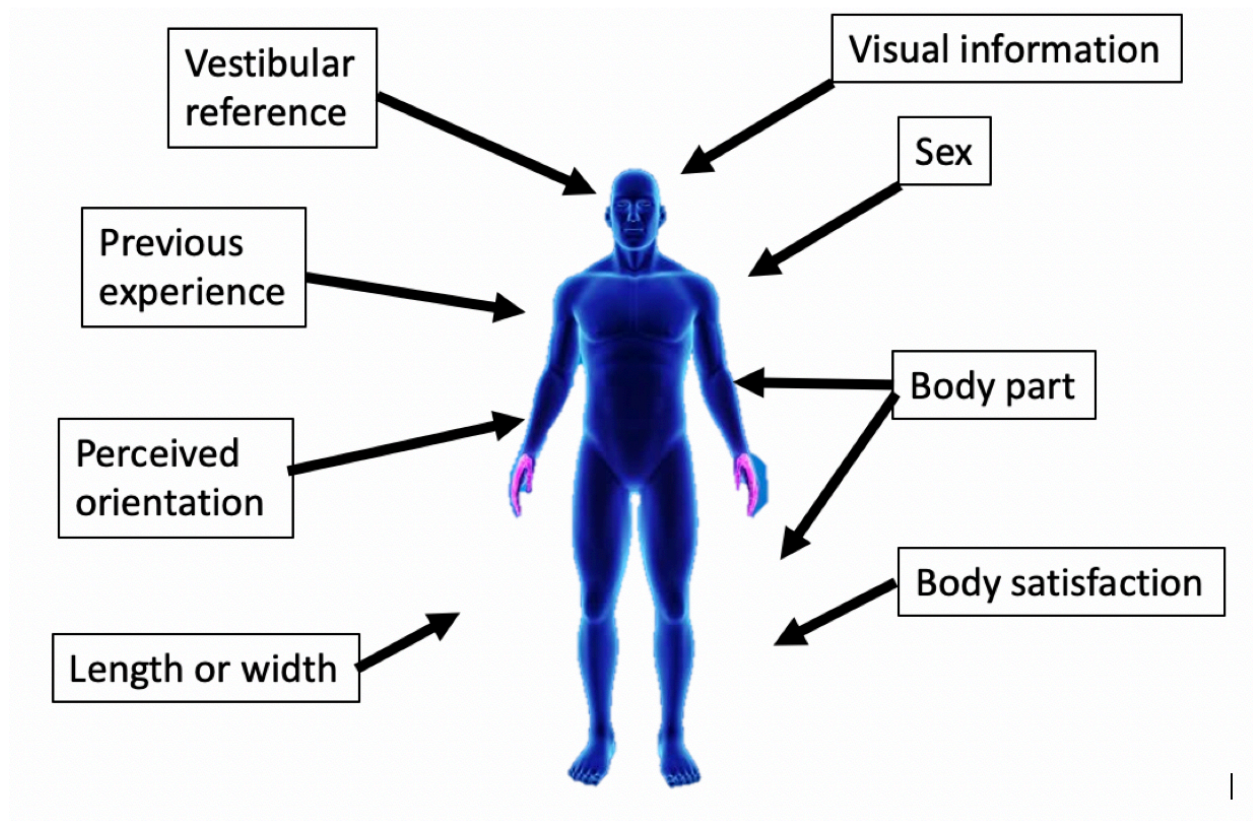


Figure 7.1. Components involved in body size perception and representation. Perceived body size is a complex process that combines several of these factors to construct, build up, and map the body in the brain. Models that implement these factors can be created to unravel the complexities involved in how the brain perceives the body.

7.2. What Determines Perceived Body Size / What My Findings Mean

My studies have shown that perceived body size depends on sex, body satisfaction, body part, dimension, orientation, viewpoint, previous experience, visual information, and vestibular signals as indicated diagrammatically in Figure 7.1. From this, we can begin to unravel the complexities that are involved in how the brain perceived the body by creating models that implement these factors. These findings provide support to the recent models of body representation that suggest there are interactions between body schema and body image for constructing internal maps of the body in the brain (Ambroziak et al., 2018; Caggiano, 2020; Carruthers, 2008, 2009; de Vignemont, 2010; Gadsby, 2018; Mora et al., 2018; Pitron et al., 2018; Sadibolova et al., 2019).

My findings increase our understanding of how fundamental sensory processes can be used to alter perceived body size. These studies will lead us to a better understanding of multisensory processes that determine how the body is represented in the brain. By understanding how the internal representation of the body is distorted and can be manipulated, we can understand the plasticity and flexibility of the brain, as well as how it can accommodate and recover from sensory manipulations (both through natural development or by laboratory manipulations). This will allow us to use this information in situations where it is desirable to introduce a change in perceived body size.

7.3. Possible Limitations

7.3.1. Image and Distortion Stimuli

The main limitation of these studies surrounds the experimental methods and stimuli used. The first being that the images used were only two-dimensional whereas the body is three-dimensional. This could lead to a loss of information about the full shape of the body, which may have resulted in less relatability and realism. Secondly, the images were distorted in a single dimension at a time rather than by distorting both dimensions. The distortion was also applied across the whole image instead of distorting particular aspects of the body in a way that could be more realistic to how and where size changes or may be a concern. Though it could be possible that participants were still basing their judgments on the overall size, it seems unlikely because the results did not show any direct overall aspect ratio effects (if something was perceived as wider, it did not automatically mean that it was also perceived as shorter). The dimensions are perhaps not completely independent but since the stimuli were only distorted in a single dimension at a time and measurements were collected separately, it seemed more appropriate to report and interpret the results individually.

7.3.2. Number of Trials and the QUEST

The number of trials tested, and the QUEST method used in these experiments are also possible limitations that may impact the estimates of accuracy obtained for each participant. The QUEST is a staircase method that hones in on its estimate of thresholds. If a participant makes an error in entering their response, the QUEST can take some time to recover. A larger number of trials would make this technique less sensitive to response errors and could provide more reliable

estimates. However, more trials take longer time and the choice of trial number is always a balance between collecting useable data and stretching participants' tolerance levels.

7.3.3. Body Satisfaction Measurement

Two main limitations in my studies when exploring the effect of body satisfaction on body size perception are that the number of participants in my experiments did not allow for a complete range of BSQ scores and when the participants were broken down into BSQ group and sex, the sample sizes became very small. Bigger sample sizes would likely provide a wider range of scores that would allow for a more extensive examination of how body satisfaction impacts perceived body size, including more reliable correlations. Having a greater number of participants in general would also help to ensure that any potential limitations are not affecting the results and conclusions made. There are also a few limitations specific to the questionnaire used to measure body satisfaction. I used the Body Shape Questionnaire (Cooper et al., 1987) that was not designed for males and has some questions written specifically for females. This may have caused the scores for males to be underestimated. The questionnaire was also designed with assessing clinical populations in mind which again might have resulted in lower scores compared to a questionnaire that was designed to measure body satisfaction in healthy populations. Honesty when answering the questionnaire is critical for obtaining an accurate score but participants may have been reluctant to give a true answer if they considered the questions too personal or too sensitive of a topic.

7.3.4. Participants

Using York University's Undergraduate Research Participant Pool (URPP) involves some rather unmotivated participants compared to selecting subjects from a more motivated group, such as graduate students. This is another potential limitation that may have caused less consistent and reliable data. Messier data could have resulted because participants may have lacked interest or understanding about how to properly complete the experiments. The URPP also provides only a limited selection of the population being mostly being around 20 years old and from a restricted range of backgrounds. The lack of diversity could have impacted the results and limited the extent to which potentially important attributes, such as age, BMI, weight, height, body part size, body satisfaction, could be considered.

7.4. Future Directions of Research

These studies suggest a variety of different directions for future research. In addition to the experiment-specific possibilities mentioned in each chapter, this section will cover the general directions that future research could take.

7.4.1. Extending Current Experiments

Future research could further explore the factors investigated in these studies to extend my findings. A greater range of orientations and viewpoints could be tested to determine the tuning of body size accuracy across more ambiguous positions of greater or lesser familiarity. Testing additional body parts would also be useful to gain a complete picture of what baseline inaccuracies exist in the representation of the body in the brain. Different technologies, like virtual reality, augmented reality, holograms, and three-dimensional body scanning, could be

used to create and display more sophisticated testing stimuli. Using additional ways to apply distortions to the stimulus, simulating for example pregnancy, old age, different body types etc... is an important direction for future research to take if comprehensive predictions of distortions of the perception of people's bodies and they might be helpfully manipulated are to be made.

7.4.2. Other Sensory Methods of Distorting the Body

Testing perceived body size accuracy after perceived body size is altered using other sensory manipulations, such as proprioceptively with tendon vibration, visually with live video, mirrors, or lenses, and multisensory with rubber hand or out-of-body illusions, would add to the understanding of how malleable and changing body representation can be and how it can influence body size perception.

7.4.3. Immersive and Interactive Manipulations

In order to create realistic feelings of body size distortions, experiments that use situations that are interactive, immersive and involving multisensory processes could be done in order to create realistic feelings of body size distortions in a more natural setting. Some possible options would be having participants wear fat suits or use virtual reality technology to remove them from themselves or to create virtual representations of their own body. The other set of situations that falls into this category of experiments is studying groups that actually do experience a significant change in their actual body size, such as pregnant women or people who have undergone plastic surgery such as following gastric bypass surgery. In these real-life situations, participants could have their perceived body size accuracy measured on a frequent

basis (at least once a month) in order to examine the time course of how accuracy values might be impacted during actual body size changes.

7.4.4. Comparisons

It would be useful to compare the different methods used to measure body size within the same sample. This would provide insight into how task type affects the results and how methodological issues may impact the findings. Comparing healthy and clinical populations using my method and design would also be a useful direction to explore, especially for research areas that typically use more subjective tasks to assess body perception. It would allow for better understanding of how body size is perceived in eating disorder individuals by providing an objective, implicit measure of perceived body size at the level of the internal body representation rather than only assessing the conscious and emotional aspects of body image.

7.4.5. Clinical Directions

Knowledge that the brain and body representation are highly plastic, flexible, and capable of being altered, and understanding the occurrence of body size distortions and how they are modeled occur provides potential research directions that might be able to help counteract distortions in body representation that occur clinically. It might be possible to alter and retrain the inaccurate representations to become more accurate using the methods and techniques used in my experiments.

7.5. Conclusions

Three overall conclusions can be drawn from the results of the experiments in this dissertation. First, it can be concluded that perceived size distortions exist in general – independent of sex and population type. Second, it is clear that many factors impact body size accuracy and that these factors can be used for understanding and mapping the body in the brain. Third, body size perception is malleable and capable of changing at the level of the internal body representation. Taken together these findings emphasize that perceived body size is critical for understanding body representation.

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APPENDIX A:

Disclaimer for Coauthored Chapters

Chapters 2, 3, and 4 in this dissertation have been published with my supervisor Laurence Harris as coauthor on all three. Laurence is also a coauthor for Chapter 5, which has been submitted for publication, and for Chapter 6, which is currently being written up for publication.

Isabella Lim (Chapter 5) and Deborah Alexe (Chapter 6) were undergraduate students that I co-supervise and who assisted me with data collection for my experiments. I conceived every study and designed the experimental methodology. Laurence and I devised and created the experimental methods, stimuli, and programming. I performed the experiments and collected the data for all chapters, with assistance from Deborah and Isabella for Chapters 5 and 6. I analyzed all of the data and wrote the manuscripts.