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UMI
BODY IMAGE DURING ADOLESCENCE:
BEHAVIOURAL AND NEUROIMAGING STUDIES

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July 2008

A thesis submitted to McGill University in partial fulfillment of the requirements of the degree of Doctor of Philosophy

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Acknowledgements

This doctoral dissertation is the culmination of countless hours of blood, sweat, and tears. Although my name is printed on the cover of this thesis, this work is the result of many a collaboration, both professional and personal. I would like to offer my heartfelt gratitude to my supervisor, Tomáš Paus, a man of boundless curiosity, supreme intellect and, perhaps most importantly, unwavering patience and dedication. His guidance, support, and friendship during this long journey has helped me to become a confident, resourceful and, hopefully, interesting scientist and person. I also wish to thank Gabriel Leonard for his collaborative spirit, gentle advice, and professional and emotional support during these past few years. To Rhonda Amsel, my statistics guru, I express my thanks for her willingness to answer any question, no matter how ridiculous, and for her calm, measured insight into my work. I would also like to acknowledge Simon Duchesne for his dedication, which knows no geographical boundaries, and his mathematical expertise, without which much of my work would simply not have been possible.

I would also offer my appreciation to Louis Collins, Zdenka Pausova, and Robert Zatorre for their invaluable comments about my work throughout the years. The studies included in this dissertation could not have been completed without the assistance of a number of individuals who were essential during the data acquisition and analysis process, namely, Celine Amiez, Chadwick Boulay, Candice Cartier, Jen-Kai Chen, Michael Ferreira, Kristina Martinu, Eileen Qian, John Totman, Keith Worsley, and the entire team at the CEGEP de Jonquiere. Thank you to Sidonie Penicoud for her assistance in translating material for this thesis and to Annie LeBire, Line Gingras, and Susan Crinion for their administrative support. I would also like to acknowledge the hundreds
of volunteers and their families that participated in these studies; their willingness to explore the unknown with me made all of this possible.

My doctoral studies would have been simply unbearable without the shoulders of my Neuro family including Julie, Jean, Joyce, Saima, Maria, Ariana, Sidonie, and Penelope, so I would like to thank them for all of their encouragement. To my dear friends, Allison Wright, Yuka Nakamura, Cate Cuttle, May Fuh, Margaret Pycherek, and Jennifer Plath, my thanks for their enduring friendship, understanding, and patience.

To my sister, June Lee-Kim, I offer my thanks for all of her reassuring and practical advice. To my brothers, Victor, Edward, and Paul, I offer my gratitude for the many dinners, long-distance technical assistance, and household advice. And to my nieces and nephews, my thanks for keeping me honest and reminding me to laugh at life’s absurdities.

I would also like to acknowledge my brother-in-law, Gilbert Lee-Kim. Of all of the things that I learned during my years as a graduate student, perhaps my most enduring lesson was learned from a man who lived his final year with such faith, grace, and dignity. He always supported me in all of my academic endeavours and he taught me much about living life to its fullest and accepting that which we cannot change.

Finally, I would like to dedicate this dissertation to my parents, Winston and Regina Aleong. Over the years, their encouragement, confidence, pride, and love have seen me through many a tearful and uncertain moment. Their understanding and never-ending support has led me to this point in my life and I would offer them my deepest thanks and love.
Abstract

The primary objective of this thesis was to investigate body image at both the behavioural and neural levels. We describe three studies aimed at: (1) developing a novel digital methodology with which to assess perceptual aspects of body image during adolescence; (2) investigating perceptual accuracy and sensitivity to changes in the size/shape of body images among healthy adolescents; and (3) identifying the neural mechanisms of body perception using functional magnetic resonance imaging (fMRI). A novel library of digital images of adolescent bodies was created and used to characterize natural covariations in body size and shape using principal components analysis. Identified principal components were used to morph body images in a realistic manner to generate larger or smaller bodies. These morphed body-image stimuli were then used in a behavioural investigation of self body-image perception among adolescents. Male and female adolescents overestimated the size of their bodies. When compared with males, females overestimated their body size to a greater extent and showed greater sensitivity in detecting changes in body size. Overestimation of body size and detection sensitivity increased with subject age. Detection sensitivity decreased as a function of subjects’ body mass index (BMI). In order to identify the underlying neural mechanisms of these effects, functional block-design and fMR-adaptation experiments were completed in healthy young adults. During both experiments, females, and not males, showed greater fMR signal in the right versus left hemisphere in the extrastriate body area (EBA) and fusiform body area (FBA). During the block-design experiment, females also demonstrated greater right EBA response compared with males. Observer BMI modulated the EBA hemispheric effect in both experiments. A significant recovery from adaptation was found.
in EBA and FBA with body-image morphing, indicating that both regions were sensitive to body-size changes. Ultimately, we demonstrated the successful use of a novel body-morphing method for the assessment of body image, established that sex, age, and BMI modulate accuracy of self body-size estimation and detection of changes in body size, and described evidence of EBA and FBA as the likely neural substrates of these behavioural effects.
Résumé

L’objectif principal de cette thèse fut d’examiner l’image corporelle aux niveaux comportemental et neural. Nous décrivons trois études ayant visé à : (1) développer une nouvelle méthodologie digitale permettant d’évaluer les aspects perceptuels de l’image corporelle pendant l’adolescence; (2) examiner l’exactitude perceptuelle et la sensibilité face à des changements au niveau de la taille et de la forme de l’image corporelle chez des adolescents en santé; et (3) identifier les mécanismes neuraux responsables de la perception corporelle à l’aide d’imagerie par résonnance magnétique fonctionnelle (IRMf). Une nouvelle bibliothèque d’images digitales de corps adolescents a été créée et utilisée pour caractériser les covariations naturelles qui existent entre la taille et la forme des corps en utilisant une analyses en composantes principales. Des composantes principales ayant été identifiées préalablement furent utilisées pour métamorphoser des images corporelles d’une manière réaliste dans le but de générer des corps plus petits ou plus grands. Ces stimuli d’images corporelles métamorphosées furent ensuite utilisés dans une expérience comportementale portant sur la perception de l’image corporelle de soi chez les adolescents. Les adolescents et les adolescentes ont surestimé la taille de leurs corps. Comparées aux adolescents, les adolescentes ont plus amplement surestimé leur taille corporelle et ont manifesté une plus grande sensibilité de détection face à des changements au niveau de la taille corporelle. La surestimation de la taille corporelle et la sensibilité de détection ont augmenté avec l’âge du sujet. La sensibilité de détection a diminué en fonction de l’indice de masse corporelle (IMC) du sujet. Afin d’identifier les mécanismes neuraux sous-jacents à ces effets, des expériences d’IRM fonctionnelle de plan bloc et d’adaptation furent effectuées chez des jeunes adultes en santé. Pendant les
Contributions of Authors

I am the first author on the manuscripts that comprise Chapters 2, 3, and 4. My role in all of the studies involved the design of behavioural and neuroimaging protocols, subject recruitment, data acquisition and analysis, interpretation of the data, and writing of the manuscripts. As my graduate advisor, Tomáš Paus oversaw all of the studies, provided feedback on the design of the experiments, aided in the interpretation of the data, and provided feedback on the manuscripts.

For the work described in Chapter 2, Simon Duchesne was involved in the design and creation of the principal components analysis model and provided feedback on the manuscript.

For the work described in Chapter 3, Rhonda Amsel contributed to the statistical analysis and interpretation of the data, as well as provided feedback on the manuscript. Gabriel Leonard contributed to the design of the behavioural experiment and provided feedback on the manuscript. Zdenka Pausova provided feedback on the manuscript.
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Chapter 1

Literature Review
1.1 Introduction

The human body form has long been considered a work of art. For example, Michelangelo immortalized the body form in his sculpture *David*. Society's artistic appreciation of the body has, in recent years, been mirrored by science's appreciation of the inherent biological complexities of the body and its image. The human body is the most basic physical instrument by which one may interface with his/her environment, whether it be internal or external. The body is recognized as an essential conduit through which one establishes a sense of self relative to others (e.g., my body versus another's body) as well as agency (e.g., my action versus another's action). Furthermore, the body may be used to communicate fundamental information about the identity, sex, actions, emotions, and even intentions of others. Yet, it is the communication between the human body and brain that allows for the recognition, integration, and interpretation of sensory signals to formulate a cohesive understanding of the body, whether it is of one's self or that of another.

It has only been in the last century that researchers have finally begun to explore the relationship between the human brain and body. Through clinical case studies and experimental research, they have begun to conceptualize the "who, what, where, when, and why" of body perception. Scientists have begun to explore such body-related concepts as the self-other body distinction, multiple and independent components of body representation, body-selective brain regions, and the temporal integration of body-related inputs. In this dissertation, we will attempt to investigate one aspect of body perception, namely, the visual processing of body form.
1.2 Study Objectives and Rationale

The primary objective of this dissertation was to investigate the behavioural and neural mechanisms underlying human perception of body size and shape. In order to achieve this goal, we examined human behaviour and brain function as it pertains to the visual perception of body size and shape. We assessed behaviourally accuracy in self body-size estimation and detection sensitivity to changes in body size. We also examined body-responsive brain regions for their sensitivity to changes in body size and shape. Moreover, we were interested in the potential influence of sex, age, and body mass index (BMI) on both behaviour and brain function. Our primary population of interest was adolescents between the ages of 10 and 17 years. Adolescence represents an experimentally interesting period of investigation as during this period there are: (1) dramatic physical changes in the adolescent body (Dai, Labarthe, Grunbaum, Harrist, & Mueller, 2002; Rogol, Roemmich, & Clark, 2002; Tanner, Whitehouse, & Takaishi, 1966), (2) significant sexual maturation (Marshall & Tanner, 1970; Marshall & Tanner, 1969), and (3) developmental changes in brain structure (Giedd et al., 1999; Paus et al., 1999). Given these physical changes, it is of great experimental interest to assess adolescents’ cognitive impression of their body size and shape during this developmental period. Rationale for this investigation into human body-size perception may also be found in clinical disorders such as anorexia and bulimia nervosa, obesity, schizophrenia, epilepsy, and migraine.

Eating Disorders

The relationship between body-size perception and eating disorders has been
explored extensively over the past five decades with Hilde Bruch being the first to
describe body-image dysfunction, including reduced accuracy in body perception, as a
fundamental component of anorexia nervosa (Bruch, 1962). In support of this hypothesis,
several studies have described overestimation of real body-size by patients diagnosed
with anorexia and bulimia nervosa when compared with control groups (Cooper &
Taylor, 1988; Gardner & Bokenkamp, 1996; Shafran & Fairburn, 2002; Slade & Russell,
1973; Sunday, Halmi, Werdann, & Levey, 1992; Szymanski & Seime, 1997; Tovee,
Benson, Emery, Mason, & Cohen-Tovee, 2003), as well as an association between the
degree of body-size overestimation at hospital discharge and the likelihood of relapse in
anorexia nervosa (Slade et al., 1973). Overestimation of body size by females adolescents
has also been identified as a predictor of higher eating-disorder scores (Gardner, Stark,
Friedman, & Jackson, 2000). In light of these findings, it is clear that a thorough
understanding of body-size perception, including behavioural and neural mechanisms,
may provide insight into the etiology, development, and treatment of eating disorders that
typically strike during adolescence (Hsu, 1990).

Obesity

Body-size perception may also play a vital role in our understanding of obesity. In
recent years, a dramatic increase in the prevalence of overweight and obese adolescents
and adults has been observed (Flegal, Carroll, Ogden, & Johnson, 2002; Ogden et al.,
2006; Ogden, Flegal, Carroll, & Johnson, 2002; Strauss & Pollack, 2001; Thompson,
Baxter-Jones, Mirwald, & Bailey, 2002; Tremblay, Katzmarzyk, & Willms, 2002). This is
especially interesting in light of some evidence suggesting that obese individuals may
overestimate their real body-size as well as show reduced sensitivity to body-size changes
There is growing interest, therefore, in exploring potential links between obesity and impairment in body-size perception, particularly among adolescents, vis-à-vis the potential contributing role that one has on the other.

**Other Neurological Disorders**

Other neurological and psychiatric disorders such as epilepsy and migraine have been associated with rare illusions related to body size such as microsomatognosia and macrosomatognosia (Blanke, Ortigue, Landis, & Seeck, 2002; Kew, Wright, & Halligan, 1998; Leker, Karni, & River, 1996; Podoll & Robinson, 2000; Todd, 1955). Illusions of body-part enlargement and shrinkage have been reported as components of migraine and epileptic seizure aura (Leker et al., 1996; Podoll et al., 2000). In addition, patients with paranoid schizophrenia or schizoaffective disorder have underestimated the size of their body parts (Priebe & Rohricht, 2001).

**Adolescence**

Thus far, we have made note of studies that explored body-size perception in the context of psychiatric or neurological dysfunction. An understanding of body-size perception in *healthy* populations, particularly adolescents, may prove essential in identifying changing patterns of body perception, the result of developmental influences. Among adolescents, a relationship between age and body-size overestimation has been reported, suggesting a potential developmental impact on the accuracy in body-size estimation (Halmi, Goldberg, & Cunningham, 1977). Adolescence, therefore, represents a period of potential intersection between eating disorders, obesity, and healthy human
development, thereby making our investigation of adolescent body-size perception both relevant and timely with clear potential for clinical applications.

In order to achieve our goals, we designed and executed three studies which involved the: (1) development of an adolescent-specific body-morphing tool with which to generate body-image stimuli for future experiments, (2) psychophysical examination of self body-size perception among healthy adolescents, and (3) identification of potential neural mechanisms underlying human body-size perception. In this dissertation, we examined body-size perception of “self” and “other” individuals in Chapters 3 and 4, respectively. It should be noted that, although body-size perception of “self” versus “other” may be separate and distinct processes, we believe that both studies offer insight into the wider concept of body-form perception.

1.3 Operational Definition of Body Representation

In order to review the existing literature about one’s perception of the human body, we must first establish an operational definition of the precise body parameters that will be examined. Historically, various terms have been used to define a representation of the human body including body schema, body experience, body image, body concept, somatopsych, image of the body ego, perceived body, and body awareness (Cumming, 1988). The conceptual confusion surrounding this research field has only increased through the often interchangeable use of such terms within a given study and the discrepancies in the definition of a given term between studies. Most importantly, these terminologies vary in their constituent aspects of body representation. We begin by
reviewing some of the existing models and terminology of body representation in the hopes of establishing an operational definition of our variables of interest for this dissertation.

Some of the earliest studies exploring body representation date back to the late nineteenth and early twentieth century with the work of Bonnier (Bonnier, 1905) and Munk (Munk, 1890 – see review Denes, 1989). Bonnier was among the first to make the distinction between a personal sense of existence and the spatial orientation of the body in the external world, the latter concept also having been discussed by Munk. Both described the importance of sensory input in the formation of these body representations, with Munk also pointing out the essential nature of the parietal lobes in maintaining body orientation by comparing sensory afferences with previously stored sensations in the sensory motor cortex.

One of the first true models of body representation was described by Head and Holmes (Head & Holmes, 1911). In this early work, the authors proposed two distinct body schema that encode a body posture model to which all posture and position changes are subsequently compared (i.e., postural schema), and a body surface model which may be used for the localization of body stimulation (i.e., surface schema). They suggested that changes in body posture are measured at a preconscious level against preceding postures or movements, and the result of this comparison “rises into consciousness as a measured postural change” (Head et al., 1911; p.187). The authors concluded that lesions of the cerebral cortex and, in particular, the sensory cortex may affect negatively the processing of incoming sensory impulses such that the reconciliation of incoming sensory signals with the current body schema is faulty.

Throughout the twentieth century, the concept of body representation has evolved
with many researchers having proposed multiple representational models of the human body (Gallagher, 1995; Paillard, 1980; Sirigu, Grafman, Bressler, & Sunderland, 1991; Slade, 1988; Smythies, 1953). These multiple representations have been often described as conceptually distinct and interactive in their generation of a holistic view of the human body. Of particular importance, later models began to make the distinction between one’s own body and those of others.

For example, in the mid-1950’s, Smythies made the distinction between the “perceived body”, “body-image”, and “body-concept”. The “perceived body” was described as the conscious “totality of all somatic sensa available to inspection” (Smythies, 1953; p.132) with respect to the body, including proprioceptive input as well as sensation of the body surface. Smythies also claimed that the perceived body and the physical body existed as separate entities that are not necessarily coincident as often claimed by the philosophy of naïve realism. In contrast, “body-image” was identified as the image of a human body, whether of one’s own or that of another individual, derived from visual, mental, or memory sources. An individual’s “body-concept” was defined as one’s memories and beliefs regarding his/her own physical body.

Other models include Paillard’s two-part model of body representation that describes distinct mechanisms to process the “where” and “what” aspects of body representation; deficits in these systems could result in difficulties in body-part localization or body-part identification, respectively (Paillard, 1980). In contrast, Gallagher defined “body image” as a conscious set of beliefs about the body including perceptual, conceptual, and emotional aspects; “body schema” was described as a holistic representation of the body in space, which is updated by various sensory inputs (Gallagher, 1995). Sirigu and colleagues suggested the existence of at least four
representations that contribute to body knowledge including: (1) a lexical or semantic representation that includes knowledge about the names and functional relationships between body parts; (2) a visuospatial representation (i.e., body structure) encompassing one's own body as well as bodies in general; (3) a dynamic body-reference system that codes relative changes in body-part position with regards to other body parts and to the external space through sensory, vestibular, and visual afferences; and (4) a motor representation that aides in the generation and maintenance of the spatial representation of the body (Sirigu et al., 1991).

Many of these models were based upon clinical findings from patients suffering from deficits in body representation including an inability to localize, name, or acknowledge ownership of various body-parts. Body representation may also be assessed, however, from a more psychological perspective. A number of psychological studies have established a broader model of "body image" that includes: (1) a conceptual component of bodies in general, (2) a perceptual component including body size and shape, and (3) an emotional or attitudinal component (Gallagher, 1995; Garner & Garfinkel, 1981; Skrzypek, Wehmeier, & Remschmidt, 2001; Slade, 1988).

As stated in the introduction, our primary objective is to investigate human body-size perception, both of the individual (Chapter 3) and that of others (Chapter 4). In the context of existing models of body representation, this may be viewed as an exploration of Smythies' and Gallagher's concepts of body image, Sirigu's concept of a visuospatial representation, or the perceptual component of the broad "body image" concept used in various psychological studies. For the sake of clarity, we will consider "body image" to be a multidimensional concept that consists of at least three distinct components including conceptual, perceptual, and emotional components. Here, we intend to investigate the
perception of body size and shape as representative of the perceptual component of “body image.”

1.4 Methods and Techniques

1.4.1 Body-Size Perception

The assessment of human body-size perception among adolescents and adults has involved the use of various techniques that range in their degree of complexity from simple self-report to complex computer-based algorithms. These techniques may be broadly categorized as: (1) tools that do not utilize the visual presentation of a human body, (2) tools that make use of a representative body silhouette or human figure, and (3) tools that utilize the distortion of real body-images. Please refer to Table 1.1 for a listing of techniques that represent each of these three categories.

Even with the advent of more complex computer-based techniques, relatively simple methods including subject self-report (Brener, McManus, Galuska, Lowry, & Wechsler, 2003; Elgar, Roberts, Tudor-Smith, & Moore, 2005; Hauck, White, Cao, Woolf, & Strauss, 1995; Talamayan, Springer, Kelder, Gorospe, & Joye, 2006; Wang, Patterson, & Hills, 2002), the image-marking technique (Askevold, 1975), and the visual size-estimation technique (Reitman & Cleveland, 1964; Slade et al., 1973) continue to be used. These techniques are often considered advantageous in that they: (1) involve minimal physical equipment (e.g., pen and paper, a portable bar and lights), (2) require few financial resources, (3) can be used in field-type situations (e.g., schools, hospitals, participant homes), and (4) can be implemented rapidly with minimal subject or tester training so as to acquire large amounts of data. For example, the image-marking
<table>
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<tr>
<th>Category Type</th>
<th>Technique</th>
<th>References</th>
</tr>
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<tr>
<td>Tools that do not utilize the visual presentation of a human body</td>
<td>• self-report of height and weight measurements</td>
<td>(Brener et al., 2003; Elgar et al., 2005; Hauck et al., 1995; Talamayan et al., 2006; Wang et al., 2002)</td>
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<td>• image-marking technique</td>
<td>(Askevold, 1975)</td>
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<td>• adjustable light-beam method</td>
<td>(Ruff &amp; Barrios, 1986; Thompson &amp; Spana, 1988; Thompson &amp; Thompson, 1986)</td>
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<td></td>
<td>• kinaesthetic size-estimating apparatus</td>
<td>(Gleghorn, Penner, Powers, &amp; Schulman, 1987)</td>
</tr>
<tr>
<td></td>
<td>• subjective body-dimensions apparatus</td>
<td>(Gila, Castro, Toro, &amp; Salamero, 1998)</td>
</tr>
<tr>
<td></td>
<td>• visual size-estimation technique</td>
<td>(Reitman et al., 1964; Slade et al., 1973)</td>
</tr>
<tr>
<td>Tools that make use of a representative body silhouette or human figure</td>
<td>• Body Rating Scale (BRS)</td>
<td>(Sherman, Iacono, &amp; Donnelly, 1995)</td>
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<td></td>
<td>• Body Image Assessment (BIA) procedure</td>
<td>(Williamson, Davis, Goreczny, &amp; Blouin, 1989)</td>
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<td></td>
<td>• Figure Rating Scale (FRS)</td>
<td>(Stunkard, Sorenson, &amp; Schulsinger, 1983)</td>
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<td>• Collins pictorial figures</td>
<td>(Collins, 1991)</td>
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<tr>
<td>Category Type</td>
<td>Technique</td>
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<tr>
<td>Tools that utilize the distortion of real body-images</td>
<td>• adjustable distortion mirror</td>
<td>(Traub &amp; Orbach, 1964)</td>
</tr>
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<td></td>
<td>• photograph, film, television, video-based distortions</td>
<td>(Allebeck, Hallberg, &amp; Espmark, 1976; Freeman, Thomas, Solyom, &amp; Hunter, 1984; Freeman, Thomas, Solyom, &amp; Koopman, 1985; Glucksman &amp; Hirsch, 1969; Probst, Van Coppenolle, Vandereycken, &amp; Goris, 1992; Stiles &amp; Smith, 1977)</td>
</tr>
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<td>• computer-based morphing methods</td>
<td>(Aleong, Duchesne, &amp; Paus, 2007; Benson, Emery, Cohen-Tovee, &amp; Tovee, 1999; Dickson-Parnell, Jones, Braddy, &amp; Parnell, 1987; Gruber, Pope, Jr., Borowiecki, &amp; Cohane, 1999; Harari, Furst, Kiryati, Caspi, &amp; Davidson, 2001; Letosa-Porta, Ferrer-García, &amp; Gutiérrez-Maldonado, 2005; Sands, Mascotte, &amp; Armatas, 2004; Schlundt &amp; Bell, 1993; Shibata, 2002; Smeets, 1999; Stewart, Williamson, Smeets, &amp; Greenway, 2001)</td>
</tr>
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</table>
technique involves a subject using a pencil to mark on a hanging paper the relative location of body-points (e.g., edge of waist) indicated by the experimenter (Askevold, 1975). The experimenter subsequently records the true distance between the body-points and any discrepancy in distance is assessed (Askevold, 1975).

Although the adjustable light-beam method (Ruff et al., 1986; Thompson et al., 1988; Thompson et al., 1986), the kinaesthetic size-estimating apparatus (Gleghorn et al., 1987), the subjective body-dimensions apparatus (Gila et al., 1998), and the visual size-estimation technique (Reitman et al., 1964; Slade et al., 1973) were listed (Table 1.1) as separate methods, they all share a basic investigative principle. They all require that the subject indicate the width of a body part by manipulating directly or through an experimenter: (1) the distance between portable callipers, lights, rings, or vertical markers (Gila et al., 1998; Gleghorn et al., 1987; Reitman et al., 1964; Slade et al., 1973) or (2) the width of a beam of light (Ruff et al., 1986; Thompson et al., 1988; Thompson et al., 1986). Typically, these methods involve either the estimation of individual body-parts at any given time (Gleghorn et al., 1987; Reitman et al., 1964; Slade et al., 1973) or the simultaneous estimation of multiple body-parts (Gila et al., 1998; Thompson et al., 1988; Thompson et al., 1986). Accuracy in body-size perception is assessed by calculating the discrepancies between subject-derived widths and the real widths of the body parts as collected by the experimenter. Some studies have implemented use of a body perception index (BPI), which may be calculated by the following formula [perceived body-size/real body-size x 100] (Slade et al., 1973).

In spite of their widespread use, these techniques are still limited by their inability to: (1) address the “gestalt” of whole body-size perception since only individual body-parts are typically estimated at any one time and (2) provide a realistic representation of
the subject’s body from which he/she may estimate his/her body size (Benson et al., 1999; Harari et al., 2001; Letosa-Porta et al., 2005). For those techniques in which the experimenter is responsible for manipulating the equipment to indicate body-part width, experimenter bias may also play a factor (Harari et al., 2001).

In light of these criticisms, techniques have been developed that utilize mock silhouettes or representative body figures in order to assess whole body-size estimation (Collins, 1991; Sherman et al., 1995; Stunkard et al., 1983; Williamson et al., 1989). Participants are presented simultaneously with a number of body images with the bodies ranging sequentially in size from thin to obese (Collins, 1991; Sherman et al., 1995; Stunkard et al., 1983; Williamson et al., 1989). The figures are often simple line drawings with minimal structural detail, thereby making the images loosely applicable to a wide range of potential subjects. Image series are selected to be sex and age-specific depending on the characteristics of the subject in question, with both child/adolescent (Collins, 1991; Sherman et al., 1995) and adult (Stunkard et al., 1983; Williamson et al., 1989) versions having been described. In most studies, subjects are instructed to select three figures that best represent their current, ideal, and most attractive body-sizes, respectively. Discrepancies between the figures selected provide some relative measure of participant body-size perception and body satisfaction.

A number of methodological shortcomings associated with figural and silhouette techniques have been identified including: (1) scale coarseness, (2) the use of ordinal measurements, (3) an inability to allow for precise body-size estimation and assessment of distortion detection sensitivity, (4) a failure of the figures to account properly for cultural and ethnic differences as the features of most figural scales are strictly Caucasian, and (5) scale inconsistencies based upon figure order (Doll, Ball, & Willows, 2004;
Gardner, 2001; Gardner, 2000; Gardner, Friedman, & Jackson, 1998; Gardner, Stark, Jackson, & Friedman, 1999c). The minimal number of available figural stimuli may result in subjects limiting their responses to a select few of the body images (Gardner, 2000; Gardner et al., 1998; Gardner et al., 1999c). Moreover, the amount of body-size change between successive figural stimuli is typically ordinal in natural (i.e., nonequal intervals), potentially restricting the statistical analysis of the data (Gardner et al., 1998; Gardner et al., 1999c). The distribution of weight in successively larger figures or silhouettes also change at differential rates for different body-parts, with little evidence that such differential body-part changes occur in reality (Gardner et al., 1998; Gardner et al., 1999c). Figural scales are also considered unable to measure quantitatively either the body-size estimation of the subject or his/her detection sensitivity to changes in body size (Gardner et al., 1998; Gardner et al., 1999c). Finally, the order of presentation of the figural stimuli (e.g., ordered, unordered, individually) may affect the ratings of perceived and ideal body-sizes (Doll et al., 2004).

In response to these criticisms, Gardner and colleagues created two new contour scales based upon the average median height and weight of American males and females at the time of development (Gardner et al., 1999c). These median measurements were used as the measure of central tendency on the contour scales and the width of this median contour was increased and decreased systematically in interval increments to generate a thirteen-figure scale. The authors concluded that one can calculate a quantitative measure of perceived body-size based upon subject contour selection since the median measurements and degree of distortion in the selected contour can be used to derive the quantitative weight of the subject’s selection. The discrepancy between the subject’s actual weight and perceived weight can be assessed quantitatively and
statistically. Nevertheless, the authors conceded that, like other figural scales, these contours scales are hampered by: (1) their inability to present realistic changes in body weight distribution with increasing or decreasing weight change and (2) their limited application to the U.S. population during the late 1980's. With the use of the median height and weight at the time of development, any change in the median body weight and height of the U.S. population would likely invalidate the scales.

Given these concerns regarding the realism of the figural and silhouette body-image stimuli, a variety of techniques have implemented the use of the real image of a subject; these techniques include the adjustable body-distorting mirror (Traub et al., 1964); photograph, film, television, or video-distortion techniques (Allebeck et al., 1976; Freeman et al., 1984; Freeman et al., 1985; Glucksman et al., 1969; Probst et al., 1992; Stiles et al., 1977); and computer-based morphing methods (Aleong et al., 2007; Benson et al., 1999; Dickson-Parnell et al., 1987; Gruber et al., 1999; Harari et al., 2001; Letosa-Porta et al., 2005; Sands et al., 2004; Schlundt et al., 1993; Shibata, 2002; Smeets, 1999; Stewart et al., 2001). With the distorting-mirror technique, the subject is situated in front of a special full-length mirror which may be adjusted so as to present a wide array of distorted body-images, varying in body height, width, and shape (Traub et al., 1964). Subjects are typically presented with a distorted body and instructed to adjust the mirror until the body image is no longer distorted but rather represents their real body-size and shape (Traub et al., 1964). Experimenters may then compare quantitatively the amount of corrective adjustment performed by the subject against that which was originally introduced by the experimenter (Traub et al., 1964).

Similarly, the photograph, film, television, and video-distortion techniques all utilize the real image of a subject, whereby distortion is introduced through the use of a
system of lenses or the physical modification of a television monitor or video camera
(Allebeck et al., 1976; Freeman et al., 1984; Glucksman et al., 1969; Probst et al., 1992;
Stiles et al., 1977). Body distortion is typically introduced in the horizontal or vertical
planes so that the presented body appears to be wider, thinner, taller, or shorter than the
real body of a subject (Allebeck et al., 1976; Freeman et al., 1984; Glucksman et al.,
1969; Probst et al., 1992; Stiles et al., 1977). Subjects are presented with an initially
distorted body and instructed to make the necessary adjustments so that the resulting
image represents his/her real body-size; discrepancies between the experimenter-induced
body distortion and the corrective picture adjustments made by the subject are typically
used as an index of accuracy in body-size estimation (Allebeck et al., 1976; Freeman et
al., 1984; Glucksman et al., 1969; Probst et al., 1992; Stiles et al., 1977).

Although the use of television and video-based techniques mark a technological
evolution in the field, they are often limited by the fact that the body distortions are linear
in nature affecting all body parts equally, resulting in a generally wider/thinner or
taller/shorter body-image. It has been argued that these horizontal and vertical changes
are overly simplistic and that more life-like simulations of body size and shape changes
must be considered (Aleong et al., 2007; Benson et al., 1999; Harari et al., 2001; Letosa-
Porta et al., 2005). Thus, a new spectrum of algorithmic changes in body size and shape
have been created (Aleong et al., 2007; Benson et al., 1999; Harari et al., 2001; Letosa-
Porta et al., 2005; Shibata, 2002; Smeets, 1999; Stewart et al., 2001). Some of the more
advanced body-morphing protocols have described the use of mathematical
transformation grids, as well as adult body prototypes derived from a library of adult
biometric reference data (Benson et al., 1999; Harari et al., 2001). In using these
morphing tools, subjects are presented with morphed images of their bodies and asked to
augment the image until their perceived body-size and shape is achieved. Differences between the initial experimenter-introduced body morphing and the subject's corrective responses are assessed.

Even the most sophisticated of the existing software are still limited by their use of adult reference data that would fail to address body-shape changes due to pubertal development. Given the importance of the adolescent period in terms of physical change, it is clear that an adolescent-specific tool for the assessment of body-size perception is essential. In addition, many of the existing distortion techniques either enlarge or shrink all body parts equally or fail to account for natural covariations between body parts, such as a correlated hip and thigh enlargement. Independent morphing of individual body-parts with subsequent smoothing of adjacent body-parts ultimately diminishes the realism of the whole body-image. Thus, there remains a scientific void in the body-size perception field that we intend to fill during the course of this dissertation.

To this point, we have described various methods of creating body-image stimuli and some broad measures to assess accuracy in body-size estimation. The specific psychophysical methodology used to evaluate subjects' perception of these body-image stimuli has yet to be discussed. Psychophysical methods that have been used previously include the method of adjustment, method of limits, staircase method, method of constant stimuli, and the adaptive probit estimation (APE) technique (Fonagy, Benster, & Higgitt, 1990; Gardner, 1996; Gardner & Boice, 2004; Gardner et al., 1996; Gardner, Friedman, Stark, & Jackson, 1999b; Gardner, Gallegos, Martinez, & Espinoza, 1989a; Gardner, Gardner, & Morrell, Jr., 1990; Gardner, Jones, & Bokenkamp, 1995; Gardner, Martinez, & Espinoza, 1987; Gardner et al., 1988a; Gardner & Moncrieff, 1988b; Gardner, Morrell, Watson, & Sandoval, 1989b). The psychophysical methods of adjustment and limits both
involve the initial presentation of a distorted body-image that is either larger or smaller than the subject’s actual body-size (Gardner et al., 1999b; Gardner et al., 1989a; Gardner et al., 1995; Gardner et al., 1987; Gardner et al., 1988a; Gardner et al., 1988b). The size of the body may be manipulated in a descending (large to small) or ascending (small to large) series by the experimenter (method of limits) or by the subject (method of adjustment) depending on whether the initial image is larger or smaller than the real body-size, respectively. Ascending or descending trials are randomly presented in order to correct for errors of anticipation. For any given trial, the amount of distortion present in the final adjusted body-size, when compared with the actual body-size, is measured. An average of ascending and descending trials may be then used as a global indicator of over- or underestimation of body size. The staircase method is a variant of the method of limits in which an image of a subject’s real body-size is initially presented and successively larger or smaller bodies are continuously presented until the subject indicates that his/her actual size has been reached (Gardner et al., 2004; Gardner et al., 1999b; Gardner et al., 1990). Once the subject has responded, the direction of body-size change is reversed until the subject, again, indicates that his/her real size has been reached. Ultimately, the perceived body-size is calculated as the average of the transition body-size points at which the subject responded.

Although widely used, the method of limits and adjustment have both been criticized for their susceptibility to an “anchor” effect (Gardner, 1996; Gardner et al., 1995). The initial stimulus size, whether it be a smaller or larger distortion, may act as an anchor, influencing the final judgment of the subject (Gardner, 1996; Gardner et al., 1995). For example, descending and ascending trials produced systematically an overestimation and underestimation of body size, respectively (Gardner, 1996). Thus,
Ascending and descending trials may represent two discrete perceptual tasks and the averaging of the results from these trials is inappropriate and inaccurate (Gardner, 1996; Gardner et al., 1995).

Consequently, greater emphasis has been placed on implementing psychophysical methods that use a signal detection approach which may account for sensory and nonsensory factors involved in body-size perception, including the method of constant stimuli and APE (Fonagy et al., 1990; Gardner et al., 1996; Gardner et al., 1995; Gardner et al., 1988b; Gardner et al., 1989b). These approaches may involve two scenarios, namely: (1) presentation of body images with (e.g., larger or smaller) or without (e.g., correct size) distortion (Gardner et al., 1990; Gardner et al., 1988b; Gardner et al., 1989b) and (2) presentation of larger or smaller distortions (Gardner et al., 2004; Gardner et al., 1996; Gardner et al., 1999b; Gardner et al., 1995). Subjects would be expected to indicate whether distortion was present or whether the presented body was larger or smaller than their real body-size, respectively. The analysis methodology has been described elsewhere (Gardner et al., 1996). In brief, the acquired data can be used to plot a best-fit cumulative normal sigmoidal function from which the experimenter may extract the subject’s perceived body-size, namely, the point of subject equality (PSE) and the subject’s sensitivity in detecting changes in body size, namely, the difference limen (DL) which is also referred to as the difference threshold. The PSE represents the distortion point at which the subject responds that the image is larger or smaller than his/her real body-size 50% of the time. The DL may be calculated as the midpoint between the distortion points at which the subject responds that the presented image is larger than him/her 25% and 75% of the time. Practically, the DL represents the degree of body-size distortion necessary to detect the difference 50% of the time.
This section has described a plethora of methods that may be used in the assessment of body-size perception. To date, a number of studies have examined the reliability and validity of these techniques including the image-marking method, the visual size-estimation technique as well as its variants, contour scales, and the video-distortion method. Reliable results have been observed with repeated testing using the Collins pictorial instrument (Collins, 1991), visual size-estimation technique (Ben-Tovim & Crisp, 1984), video-distortion method (Probst et al., 1992; Probst, Vandereycken, Van Coppenolle, & Pieters, 1995b), and computer-morphing techniques (Stewart et al., 2001). Strong intercorrelations of body-size estimations have also been reported between different body-parts and image views (e.g., front versus side) when using the image-marking method, visual size-estimation technique, and video-distortion method (Button, Fransella, & Slade, 1977; Freeman et al., 1985; Gardner et al., 1996; Pierloot & Houben, 1978; Probst et al., 1992; Slade et al., 1973).

Direct comparison of different techniques, however, has revealed mixed results. Garner and colleagues described different group results when using the visual size-estimation and distorting-photograph techniques, with only the latter showing significant differences between patients with anorexia nervosa and control subjects (Garner, Garfinkel, Stancer, & Moldofsky, 1976). Similarly, a study comparing recovered anorexics with control subjects showed inconsistent results when using the video-distortion technique, image-marking method, and kinaesthetic size-estimation technique (Lautenbacher, Kraehe, & Krieg, 1997). In contrast, in comparing their two new contour scales and the video-distortion technique, Gardner and colleagues reported acceptable validity and high test-retest reliability for the new contour scales; yet, the video-distortion method was shown to be the preferred method with relatively higher validity (Gardner et
Inconsistent findings within a given study when using different assessment techniques may indicate that these techniques measure different aspects of body-size perception (Garner et al., 1976).

1.4.2 Body Satisfaction

Numerous methods have been used to assess body satisfaction among adolescents and adults, including many that have been described previously in the context of body-size perception. These techniques include questionnaires, silhouette-based rating scales, and the video-distortion technique. Questionnaires that assess body satisfaction often use explicit queries and Likert scales to produce quantitative measures of body satisfaction. Previously used questionnaires include the Body Esteem Scale for Adolescents and Adults (BESAA; Mendelson, Mendelson, & White, 2001), the Children’s Eating Attitudes Test (ChEAT; Maloney, McGuire, & Daniels, 1988), the Eating Attitudes Test (EAT-26; Garner, Olmstead, Bohr, & Garfinkel, 1982), the Body Dissatisfaction and Drive for Thinness subscales of the Eating Disorder Inventory (EDI-2; Garner, 1991), the Body Shape Satisfaction Scale (Pingitore, Spring, & Garfield, 1997), and the Lerner Body Image Scale (Lerner, Karabenick, & Stuart, 1973). Scales such as these assess quantitatively subjects’ feelings and attitudes regarding various components of body satisfaction including appearance, weight, dieting behaviour, and desired body characteristics.

Experimental methods that have been used to assess self body-size have also been applied to assess body satisfaction. Among the most commonly used experimental techniques are the silhouette figures including the Figure Rating Scale (FRS; Stunkard et
al., 1983) and Collins pictorial instrument (Collins, 1991). With any of the experimental techniques, whether it be the figural scales, distorting mirror, or computer-distortion technique, body satisfaction may be quantified by comparing an individual’s perceived and ideal body-sizes. For the aforementioned techniques, subjects would be instructed to identify not only their perceived/current body-size but also their ideal body-size using the same procedure. Once identified, the difference between the selected figures is considered an index of body satisfaction.

1.5 General Limitations of Studies of Self Body-Size Perception

Any review of the existing literature about self body-size perception must first make note of numerous methodological limitations that call into question the veracity of many study results. These study limitations often involve: (1) the testing instruments used, (2) anchor effects, and (3) the statistical analyses. We have described a broad range of methods used to assess body perception, many of which are quite different in their approach. Some techniques such as the visual size-estimation technique do not make use of a body reference from which the subject derives his/her estimates. The mock silhouette scales, in contrast, use generic body forms as representative stimuli for all study participants. Finally, photograph, video, and computer-distortion techniques make use of a real image of a subject. In comparing the results from studies making use of such varied techniques, it is not entirely surprising that study findings are not consistent. In fact, validation and reliability assessment of multiple techniques within a given study has led to different conclusions depending on the technique used (Garner et al., 1976; Lautenbacher et al., 1997). We have described previously the inherent problems with
many of these techniques; such problems along with the lack of a gold standard method that is used across studies may account, in part, for the confusion that exists in the field.

Another key limitation of many of the body-image studies involves the failure to account for potential anchor effects. Numerous studies have established that estimated body-size values differ depending on whether a given trial is ascending or descending (Farrell, Shafran, & Fairburn, 2003; Gardner et al., 1989a; Gardner et al., 1995; Gardner et al., 1987; Gardner et al., 1988a; Gardner et al., 1989b). Thus, the averaging of ascending and descending trials may lead to artificial enhancement or suppression of results. Some studies have also gone so far as to use multiple psychophysical methods (e.g., method of adjustment and APE) and average their subsequent results (Gardner et al., 1999b).

Many of these behavioural studies are also hindered by their failure to conduct a vigorous statistical comparison between participants’ perceived body-size and their real body-size. Studies often report relative differences in the perceived body-size between study groups without verifying that the perceived body-size differs from the real body-size for each group. Although various studies report numerical overestimation values in their results, they conclude that subjects have an accurate perception of self body-size with little statistical verification (Brodie, Bagley, & Slade, 1994; Koff & Kiekofer, 1978). Even if a statistical difference has been reported between subjects’ perceived body-size and real body-size, researchers have still concluded that participants demonstrated an accurate perception of self body-size and that the “small absolute magnitude [of overestimation] is not meaningful” (Gardner, Friedman, & Jackson, 1999a; Gardner et al., 1999b; p.546). Therefore, given the multitude of methodologies used, the inherent problems with many of those methods, and fundamental anchor and statistical
issues, it is not entirely surprising that there are many conflicting studies in the existing literature.

1.6 Studies of Self Body-Size Perception

As early as the 1960’s and mid-1970’s, Franklin Shontz was among the first to begin investigating formally the ability of subjects to estimate the dimensions of body parts and the whole body using a variant of the visual size-estimation technique (Shontz, 1963; Shontz, 1965; Shontz, 1967; Shontz & McNish, 1972). Shontz and colleagues revealed that human body-parts and body figures produce different perceptual responses when compared with non-body-part objects or stimuli not recognized as body figures (Shontz, 1965; Shontz et al., 1972). For example, Shontz reported that body-part estimates were more sensitive to whether the presented image was larger or smaller than the real body-part size compared with wooden sticks (Shontz, 1965). These early findings regarding the unique perceptual nature of body parts and whole bodies led to an explosion of behavioural research over the past five decades.

As described in the previous section, studies of body-size perception have varied greatly in the type of body-image stimuli used, psychophysical method of image presentation, and calculation of resulting dependent measures. Nevertheless, we intend to summarize the behavioural findings of the field through a review of four populations, namely: (1) healthy adolescents, (2) healthy adults, (3) patients diagnosed with an eating disorder, and (4) obese individuals.
1.6.1 Adolescents and Self Body-Size Perception

In spite of growing interest in adolescent body-perception, relatively few studies have conducted a systematic psychophysical assessment of self body-size perception among adolescents, healthy or otherwise. A variety of self-report studies have attempted to assess body-size estimation accuracy among adolescents by comparing self-reported height, weight, BMI, and weight status (e.g., overweight, obese) with the actual measured values (Brener et al., 2003; Brooks-Gunn, Warren, Rosso, & Gargiulo, 1987; Davis & Gergen, 1994; Elgar et al., 2005; Fortenberry, 1992; Hauck et al., 1995; Himes & Faricy, 2001; Himes & Story, 1992; Shannon, Smiciklas-Wright, & Wang, 1991; Strauss, 1999; Talamayan et al., 2006; Tienboon, Wahlqvist, & Rutishauser, 1992; Tsiliglis, 2006; Wang et al., 2002). In comparing self-report and measured values, a number of adolescent studies have described overestimation of height (Brener et al., 2003; Fortenberry, 1992; Hauck et al., 1995; Tienboon et al., 1992; Wang et al., 2002) and underestimation of weight (Abraham, Luscombe, Boyd, & Oleson, 2004; Brener et al., 2003; Brooks-Gunn et al., 1987; Elgar et al., 2005; Fortenberry, 1992; Hauck et al., 1995; Himes et al., 2001; Himes et al., 1992; Shannon et al., 1991; Strauss, 1999; Tienboon et al., 1992; Tsiliglis, 2006; Wang et al., 2002), with subsequent underestimation of the prevalence of overweight and obesity among study participants (Brener et al., 2003; Elgar et al., 2005; Hauck et al., 1995).

Significant effects of sex have been reported with females showing greater discrepancies between self-reported and measured values (Brener et al., 2003; Davis et al., 1994; Strauss, 1999). In addition, the direction of estimation and degree of discrepancy may be influenced by subject BMI with underweight individuals
overestimating values and overweight or obese individuals underestimating values (Abraham et al., 2004; Davis et al., 1994; Hauck et al., 1995); individuals “at risk for overweight/obesity” as well as overweight and obese subjects have demonstrated greater estimation biases compared with nonoverweight and nonobese individuals (Abraham et al., 2004; Davis et al., 1994; Hauck et al., 1995; Himes et al., 1992; Shannon et al., 1991; Strauss, 1999; Tsigilis, 2006; Wang et al., 2002).

Although self-report protocols are relatively easy and inexpensive to implement, various studies have also used the distortion-mirror technique (Brodie et al., 1994), the subjective body-dimensions apparatus (Gila et al., 1998), the visual size-estimation technique (Bergstrom, Stenlund, & Svedjehall, 2000; Halmi et al., 1977; Koff et al., 1978), the adjustable light-beam apparatus (Fabian & Thompson, 1989), and film or video-distortion methods (Gardner et al., 1999a; Gardner et al., 1999b; Stiles et al., 1977) to assess the accuracy of self body-size estimation and detection sensitivity to body-size changes during adolescence. Overall, various studies have described self body-size overestimation of the whole body and/or body parts among females and males (Bergstrom et al., 2000; Brodie et al., 1994; Fabian et al., 1989; Gila, Castro, Cesena, & Toro, 2005; Halmi et al., 1977; Koff et al., 1978). Body parts that have been overestimated, in particular, include the waist, hips, buttocks, and thighs (Bergstrom et al., 2000; Gila et al., 2005). Female underestimation of body-part lengths has also been described (Halmi et al., 1977).

The aforementioned behavioural studies (i.e., not involving self-report) reported estimation values indicating overestimation of self body-size, as well as significant differences in the degree of overestimation between study groups; none of these studies used statistical measures to verify whether the degree of overestimation displayed by
subjects was significantly different from their real body-size. Two studies involving adolescents have done so (Gardner et al., 1999a; Gardner et al., 1999b). Gardner and colleagues verified statistically that adolescents overestimate their body size relative to their real body-size using PSE and BPI measures (Gardner et al., 1999a; Gardner et al., 1999b). Nevertheless, Gardner and colleagues interpreted their results as evidence of accurate perception of body size since the absolute value of overestimation was deemed to be small (Gardner et al., 1999a; Gardner et al., 1999b).

Other factors such as sex and age may impact self body-size estimation and detection sensitivity to body-size changes. Females have reported greater overestimation of body parts compared with males (Bergstrom et al., 2000). In addition, body-size overestimation and detection sensitivity to changes in body size have decreased (Gardner et al., 1999a; Gardner et al., 1999b; Halmi et al., 1977) and increased with age (Gardner et al., 1999a; Gardner et al., 1999b), respectively.

This reported overestimation of self body-parts and whole bodies has raised concern that such perception biases may not be specific to self body-size perception, but rather reflect wider body-perception biases or even general biases towards all objects. In order to address this issue of specificity, an attempt has been made to examine size perception of “other” individuals and inanimate objects. Adolescents have overestimated self body-size to a greater extent compared with “other” bodies and inanimate control objects (Koff et al., 1978), indicating that the aforementioned perceptual biases are specific to subjects’ own bodies.

Overall, one may conclude that adolescents do show a tendency to overestimate body size and that this bias is influenced by subject sex, age, and BMI. This conclusion, however, must be interpreted with caution since: (1) few studies have examined this
question statistically, (2) many of these studies are plagued with methodological variability and statistical inconsistencies, and (3) few studies have utilized adolescent-specific assessment tools.

1.6.2 Adults and Self Body-Size Perception

Adult assessment of body-size perception has utilized many of the same methods that have been previously described for adolescents. Self-report studies that compared subject-reported height, weight, BMI, and weight classification (e.g., overweight, obese) with measured values generally showed an overestimation of height (Himes & Roche, 1982; Stewart, 1982; Stewart, Jackson, Ford, & Beaglehole, 1987), underestimation of weight (Stewart, 1982; Stewart et al., 1987), and consequently, underestimation of overweight and obesity (Stewart et al., 1987). Such findings have been influenced by the subjects’ sex, age, and actual weight/BMI. For example, males overestimated their height and females underestimated their weight to a greater extent than the opposite sex (Stewart, 1982; Stewart et al., 1987). Discrepancies between self-reported and measured height and weight values have increased and decreased with age, respectively (Flood, Webb, Lazarus, & Pang, 1999; Palta, Prineas, Berman, & Hannan, 1982; Rowland, 1990; Stewart, 1982; Stewart et al., 1987). In addition, increasing discrepancies have been reported with increasing subject weight or BMI (Flood et al., 1999; Palta et al., 1982; Stewart, 1982; Stewart et al., 1987). Many of these adult results are consistent with previously described adolescent self-report studies, thereby indicating a consistency of biases from adolescence through to adulthood.

Various other techniques including the image-marking technique (Thomas &
Freeman, 1991; Whitehouse, Freeman, & Annandale, 1988), adjustable light-beam method (Thompson et al., 1988), visual size-estimation method (Dolan, Birtchnell, & Lacey, 1987; Fonagy et al., 1990; Hundleby & Bourgouin, 1993; Slade et al., 1973), distorting mirror (Brodie, Slade, & Riley, 1991), photograph-distortion technique (Farrell et al., 2003; Shafran et al., 2002), video-distortion technique (Freeman et al., 1985; Gardner et al., 1995; Gardner et al., 1999c; Kulbartz-Klatt, Florin, & Pook, 1999; Probst et al., 1992; Probst et al., 1995b; Szymanski et al., 1997), and computer-distortion technique (Kagawa, Kerr, Dhaliwal, Hills, & Binns, 2006; Pope, Jr. et al., 2000; Rowe, McDonald, Mahar, & Raedeke, 2005; Tovee et al., 2003) have been used to assess adult self body-size perception. Many studies have reported a perception bias in self body-size estimation among both males and females; this perception bias has been predominantly described as an overestimation of body parts and/or of the whole body, although some evidence of underestimation has been noted (Brodie et al., 1991; Button et al., 1977; Casper, Halmi, Goldberg, Eckert, & Davis, 1979; Dolan et al., 1987; Farrell et al., 2003; Freeman et al., 1985; Garner et al., 1976; Hundleby et al., 1993; Probst et al., 1992; Slade et al., 1973; Thompson et al., 1988; Thompson et al., 1986; Tovee et al., 2003; Whitehouse et al., 1988). Unfortunately, these studies reported mean estimation values that were larger or smaller than the actual size of subjects' bodies and then concluded that subjects over- or underestimated their body size without testing this hypothesis statistically. These studies focused primarily on comparing body-size estimation between study groups (i.e., males versus females, patients versus controls, different collection methods).

Relatively few studies have compared statistically subjects' perceived body-size with their real body-size. Of the existing studies, perceptual biases have been described
including an overestimation of body parts (e.g., waist, hips, chest), whole bodies, and muscularity (Fonagy et al., 1990; Kagawa et al., 2006; Pope, Jr. et al., 2000; Thomas et al., 1991), as well as an underestimation of body parts (e.g., thigh) and/or bodies (Fernandez, Probst, Meermann, & Vandereycken, 1994; Fonagy et al., 1990; Gardner et al., 1995). Accurate perception of certain body-parts (e.g., shoulders) has also been identified (Thomas et al., 1991). Thus, one may conclude that healthy adults, like adolescents, do show perceptual biases in estimating the size of their bodies and/or body parts; the direction (e.g., over- versus underestimation) of this perceptual bias remains to be verified.

Sex and real body-size effects have also been described in the context of perceived self body-size. Females have reported greater biases in body-size estimation than males, predominantly in the direction of overestimation (Fonagy et al., 1990; Thompson et al., 1986). Females have overestimated, in particular, the size of their chest and waist while males have underestimated thigh-size (Fonagy et al., 1990). With respect to detection sensitivity, a lower female threshold has been observed for waist detection compared with males (Fonagy et al., 1990). It should be noted, however, that other studies have reported no significant sex differences (Brodie et al., 1991; Dolan et al., 1987; Gardner et al., 1995).

In addition, a significant negative correlation has been found between the amount of self body-distortion and participants’ weight:height ratio, suggesting an influence of real body-size on the perception of body size (Pumariega et al., 1993). In fact, individuals with extreme body weight (i.e., low, high) have demonstrated a greater degree of overestimation of body width (Dolan et al., 1987).

As previously described, studies have attempted to assess the specificity of these
adult perceptual biases by examining the perception of neutral objects. Studies have described relatively accurate object size-perception (Dolan et al., 1987; Probst et al., 1995b), underestimation of object width (Fonagy et al., 1990; Probst et al., 1992), and overestimation of object size (Hundleby et al., 1993) among subjects that showed perceptual biases in body perception.

1.6.3 Eating Disorders and Self Body-Size Perception

According to the Diagnostic and Statistical Manual of Mental Disorders (2000), the term “eating disorder” includes the diagnoses of anorexia nervosa (AN) and bulimia nervosa (BN). The diagnostic criteria for AN include: (1) a refusal to maintain body weight at an acceptable weight as determined by an individual’s age and height; (2) an intense fear of gaining weight in spite of being underweight; (3) amenorrhea in postmenarcheal females; and (4) a disturbance in how body weight or shape is experienced by an individual. Anorexia nervosa may be partitioned further into binge-eating/purging and restricting types, which include individuals that engage in binge-eating or purging behaviour and those that do not, respectively.

Bulimia nervosa is characterized by: (1) regular incidents of binge eating at least twice a week for three months; (2) regular inappropriate compensatory behaviour to prevent weight gain (e.g., self-induced vomiting, fasting, excessive exercise, misuse of laxatives and diuretics) at least twice a week for three months; and (3) self-evaluation that is overly influenced by body shape and weight. Such behaviours must not coincide exclusively with episodes of AN. Bulimia nervosa is also subdivided into purging and nonpurging types; purging bulimics engage regularly in self-induced vomiting or the
misuse of laxatives, diuretics, or enemas; in contrast, nonpurging bulimics use other compensatory behaviours such as fasting or excessive exercise.

As early as the 1960's, Hilda Bruch proposed that anorexia nervosa may be characterized by: (1) a disturbance of body image of "delusional proportions" (p. 188), (2) a disturbance in the accuracy of perception or cognitive interpretation, and (3) a sense of ineffectiveness (Bruch, 1962). This inclusion of a disturbance of body image as a fundamental component of AN has led to numerous studies investigating whether patients with an eating disorder show perceptual deficiencies in their perception of self body-size when compared with healthy individuals.

Using a variety of techniques, many studies have established significant differences in body-size perception among patients with an eating disorder as well as recovered patients when compared with control groups. Female patients with anorexia and bulimia nervosa have overestimated body parts (e.g., waist, hips more so than shoulders and chest) and/or the whole body, when compared with controls, using the image-marking technique (Whitehouse et al., 1988; Wingate & Christie, 1978), visual size-estimation apparatus (Pierloot et al., 1978; Slade et al., 1973; Sunday et al., 1992), distorting-photograph technique (Garfinkel, Moldofsky, Garner, Stancer, & Coscina, 1978; Garner et al., 1976; Shafran et al., 2002), video-distortion technique (Freeman et al., 1985; Gardner et al., 1996; Szymanski et al., 1997), and computer-based methods (Tovee et al., 2003). Adolescent males with anorexia nervosa have also overestimated the size of their shoulders, hips, and thighs compared with a control group (Gila et al., 2005). Even women recovered from anorexia nervosa continue to overestimate body size when compared with controls (Lautenbacher et al., 1997). Patients with an eating disorder have also displayed significantly greater variability in their estimates of body size compared...
with control groups (Gardner et al., 1996; Garfinkel, Moldofsky, & Garner, 1979; Garfinkel et al., 1978; Pierloot et al., 1978).

It should be noted that these differences between patient and control groups reflected one of the following three patterns: (1) both groups overestimated self body-size, only the clinical group to a significantly greater extent (Freeman et al., 1985; Gila et al., 2005; Pierloot et al., 1978; Shafran et al., 2002; Szymanski et al., 1997; Tovee et al., 2003); (2) patients with an eating disorder overestimated while controls underestimated body size (Gardner et al., 1996; Garner et al., 1976; Wingate et al., 1978); or (3) patients with an eating disorder overestimated while controls were accurate in their body perception (Garfinkel et al., 1978; Slade et al., 1973; Whitehouse et al., 1988).

Differences between patients with eating disorders and controls may also extend beyond the perception of self body-size and include signal detection parameters such as the response criterion by which they determine whether body distortion is present or not. Anorexic subjects were more likely to identify distortion in an image of themselves compared with controls (Gardner et al., 1988b).

In spite of the numerous studies establishing significant overestimation biases among patients with an eating disorder, some studies have failed to detect any differences between clinical and control groups with respect to self body-size perception (Ben-Tovim et al., 1984; Button et al., 1977; Casper et al., 1979; Garner et al., 1976; Hennighausen, Enkelmann, Wewetzer, & Remschmidt, 1999; Probst et al., 1992; Probst et al., 1995b; Strober, Goldenberg, Green, & Saxon, 1979) or detection sensitivity to changes in body size (Gardner et al., 1996; Gardner et al., 1988b). Although no significant differences were found between clinical and control groups within the aforementioned studies, it should be noted that, in some of these studies, both clinical and control groups still
overestimated their real body-size in absolute terms (Ben-Tovim et al., 1984; Button et al., 1977; Casper et al., 1979; Garner et al., 1976; Strober et al., 1979). Underestimation of body size by both groups has also been detected (Fernandez et al., 1994; Probst et al., 1992). The differences, or lack thereof, between clinical and control groups refer to relative differences. They do not, however, provide statistical information regarding the significance of subjects’ over- or underestimation of their real body-size. This remains one of the main limitations of many of these studies.

Body-size perception (e.g., PSE) and the detection threshold (e.g., DL) among patients with an eating disorder, like that of healthy adolescents and adults, have been modulated by other factors including actual body-size (e.g., height, weight, BMI) and age. For example, a decrease in overestimation has been correlated with an increase in weight among anorexic subjects (Gardner et al., 1996; Slade et al., 1973). In contrast, positive correlations have been reported between body-size estimation and subject height and height:weight ratio; thus, greater overestimation was detected with an increase in height (Gardner et al., 1996). Significant negative correlations have also been reported between body-part (over)estimation and weight:height ratios (Pumariega et al., 1993) and BMI (i.e., greater overestimation with decreasing BMI) for the shoulders, waist, hips, thighs, and calves (Gila et al., 2005). Finally, a significant positive correlation has been identified between subject age (14 to 43 years) and DL (Gardner et al., 1996).

The clinical importance of body-size perception in patients with an eating disorder has been clearly demonstrated by studies that have revealed significant relationships between biases in the perception of body size and disease severity, relapse, and treatment outcome. The tendency to overestimate self body-size has been negatively associated with pretreatment weight and weight gain during treatment, as well as positively associated
with the number of previous hospitalizations and degree of denial (Casper et al., 1979). With respect to outcome, body-size estimations upon initial assessment have been negatively correlated with follow-up measures (Button et al., 1977). Patients who demonstrated large perceived body-distortions in hospital were also prone to relapse (Slade et al., 1973). In addition, patients who were classified as having a poor outcome overestimated body size significantly more than those with improved outcomes (Garfinkel, Moldofsky, & Garner, 1977).

Examination of the body perception of “other” individuals by patients with an eating disorder revealed that they overestimate the body widths of “other” individuals, but to a lesser extent than that of their own bodies (Slade et al., 1973). Furthermore, AN patients showed no significant differences in the estimation of a standard female model’s body size when compared with a control group (Garner et al., 1976). Thus, it has been suggested that, although patients may have a tendency to overestimate body sizes, they do perceive their own bodies differently when compared with those of others (Slade et al., 1973). Most importantly, comparable estimation of “other” bodies, when compared with a control group, suggests that overestimation biases among patients with an eating disorder are specific to self/body-size and cannot be generalized to all bodies.

In an examination of object-size perception, patients with an eating disorder and control subjects have estimated neutral objects equally well (Casper et al., 1979; Garfinkel et al., 1978; Garner et al., 1976). This has led to the hypothesis that body-size biases among patients with an eating disorder cannot be explained simply by a general perceptual disorder (Casper et al., 1979; Garner et al., 1976).

Some methodological limitations in the above studies should be considered. In many of the studies, the diagnostic criteria for inclusion into the study were unclear;
important demographic and disease information were often not provided such as duration of illness, symptomology, and stage of treatment, thereby leading to an assumption of patient homogeneity that may have been inaccurate (Garner et al., 1981). It is known, for example, that significant positive correlations exist between overestimation of body size and the number of days and the amount of weight gained since admission (Button et al., 1977). In addition, AN patients who exhibited regular or occasional vomiting symptoms have been described as overestimating body size to a greater extent compared with patients exhibiting no vomiting symptoms (Button et al., 1977). Thus, failure to control for these diagnostic factors may have led to an amalgamation of clinical subgroups with different patterns of body-size estimation and potential suppression of significant findings.

The control groups used in many of these studies must also be considered. Psychiatric patients with personality, neurotic, and depressive disorders have been often used as controls in AN studies without additional nonpsychiatric groups (Pierloot et al., 1978; Strober et al., 1979). This is particularly disturbing in light of evidence suggesting that greater overestimation is associated with greater neuroticism (Garner et al., 1976), a lack of self control (Garner et al., 1976), and negative mood (Kulbartz-Klatt et al., 1999). Thus, psychiatric patients may show elevated levels of body overestimation, comparable to that of the AN patients, resulting in a failure to detect any significant group differences.

In the majority of studies, the results appear to suggest that overestimation of self body-size is a component of eating disorders, even if only among a specific subset of patients or during a certain disorder phase. The data also suggest that such body perception biases are not exclusive to eating disorders and may also be present among healthy adolescents and adults. Thus, body-size overestimation may be considered an
important component of the pathology of eating disorders but a component that is not necessarily pathological.

1.6.4 Obesity and Self Body-Size Perception

According to the Centers for Disease Control (CDC), adult obesity is typically defined using adult BMI values, whereby four classifications are provided: (1) underweight (BMI < 18.5 kg/m$^2$); (2) healthy weight (18.5 kg/m$^2$ $\leq$ BMI $\leq$ 24.9 kg/m$^2$); (3) overweight (25 kg/m$^2$ $\leq$ BMI $\leq$ 29.9 kg/m$^2$); and (4) obese (BMI $\geq$ 30 kg/m$^2$). With respect to adolescents, obesity is defined using classifications that account for sex and age-related changes (e.g., body fat, height) in the physical body (i.e., underweight: < 5th percentile, healthy weight: 5th - < 85th percentile, at risk of overweight: 85th - < 95th percentile, overweight: $\geq$ 95th percentile) derived from the 2000 growth charts (National Center for Health Statistics & National Center for Chronic Disease Prevention and Health Promotion, 2000). In recent years, the prevalence of adolescent and adult obesity has increased dramatically in Canada and the United States. Over a 15-year period, Canadian men showed a 5-9% increase and women a 4-5% increase in overweight and obesity prevalence (Tremblay et al., 2002). Perhaps even more disturbing, Tremblay and colleagues described a 14-22% increase in overweight and 7-8% increase in obese children and adolescents (Tremblay et al., 2002). Over a 6-year period in the United States, children and adolescents showed a 3-5% increase in overweight prevalence (Ogden et al., 2002) while adults showed a 7% increase in obesity prevalence (Flegal et al., 2002).

With such dramatic changes in the form of the human body taking place in the
population, research studies have begun to explore the cognitive effects of obesity on body-size perception. These studies are much fewer in number, when compared with those studying eating disorders, and have reported conflicting results. Studies have reported that obese adults overestimate (Gardner et al., 1988a; Garner et al., 1976; Shipman & Sohlkhah, 1967), underestimate (Allebeck et al., 1976), or show no differences (Gardner et al., 1989a; Gardner et al., 1987; Gardner et al., 1989b) in their perceived self body-size when compared with nonobese individuals. Obese adolescents, in contrast, have underestimated their body size to a lesser extent than controls (Probst et al., 1995a). Analysis of reaction times also revealed that obese individuals performed a self body-perception task significantly faster than nonobese subjects (Gardner et al., 1988a).

Significant differences have also been identified between obese and nonobese individuals with respect to their ability to detect distortion in a body image. Obese individuals have reported heavy bodies as distorted while reporting thin bodies as not distorted (Gardner et al., 1987). In contrast, nonobese individuals have demonstrated an opposite pattern with a tendency to report heavy bodies as undistorted and thin bodies as distorted (Gardner et al., 1987). Based upon these results, obese and normal-weight subjects may hold different response biases during the performance of a self-perception task (Gardner et al., 1987). In addition to such group differences in response bias, obese subjects have shown lower sensory sensitivity in detecting distortion in body images when compared with nonobese controls (Gardner et al., 1988a).

Various studies have also explored the specificity of these perceptual biases among the obese through an examination of subjects' perception of manikins, male and female models, and neutral objects (e.g., vase, telephone, chair). No significant differences were
found between obese and nonobese subjects in the perception of manikins, human models (Gardner et al., 1987; Garner et al., 1976; Glucksman et al., 1969), or neutral objects (Gardner et al., 1988a; Garner et al., 1976; Glucksman et al., 1969; Probst et al., 1995a).

1.7 Studies of Body Dissatisfaction

So far, we have discussed extensively self body-size perception as one of the components of the wider concept of body image. Another integral component of body image involves an individual's emotions or attitudes towards the body, namely, body satisfaction. Unlike body-size perception, research into body satisfaction has achieved a much higher degree of agreement in both adolescents and adults. Three key areas of interest that we will be discussing in the context of body satisfaction are: (1) sex, (2) age, and (3) BMI.

1.7.1 Adolescent Body-Dissatisfaction

Different patterns of body dissatisfaction have been reported among adolescent females and males. Female children and adolescents have generally exhibited greater body dissatisfaction when compared with males, as identified by questionnaires and the discrepancy between perceived and ideal body-sizes (Eisenberg, Neumark-Sztainer, & Paxton, 2006; Gardner et al., 1999a; Gardner et al., 1999b; Koff, Rierdan, & Stubbs, 1990; Kostanski, Fisher, & Gullone, 2004; Kostanski & Gullone, 1998; Mendelson et al., 2001; Rolland, Farnill, & Griffiths, 1996; Rosenblum & Lewis, 1999; Sands, Tricker, Sherman, Armatas, & Maschette, 1997; Thompson, Corwin, & Sargent, 1997; Wood, Becker, & Thompson, 1996). Female children and adolescents have expressed a desire to
lose weight (Gustafson-Larson & Terry, 1992; Maloney, McGuire, Daniels, & Specker, 1989; McVey, Tweed, & Blackmore, 2004), described their ideal body-size as significantly smaller or thinner than their perceived body-size (Ambrosi-Randic, 2000; Brodie et al., 1994; Collins, 1991; Gardner et al., 1999b; Parkinson, Tovee, & Cohen-Tovee, 1998; Rolland, Farnill, & Griffiths, 1997; Sherman et al., 1995; Tiggemann & Wilson-Barret, 1998; Williamson & Delin, 2001), and reported particular dissatisfaction with their profiles, legs, stomach, hips, thighs, and buttocks (Davies & Furnham, 1986; Rosenblum et al., 1999; Salmons, Lewis, Rogers, Gatherer, & Booth, 1988). In contrast, adolescent males have shown a different pattern, whereby males have expressed a desire to either gain or lose weight (Furnham & Calnan, 1998; Maloney et al., 1989; Middleman, Vazquez, & Durant, 1998; Rolland et al., 1997) while describing their ideal body-size as larger, heavier, and/or more muscular (Cohn et al., 1987; Kostanski et al., 1998; Parkinson et al., 1998; Thompson et al., 1997) or smaller and leaner (Collins, 1991; Gardner et al., 1999b; Kostanski et al., 1998; Parkinson et al., 1998; Thompson et al., 1997) than their perceived body-size. The apparent conflict in the male desires for weight loss and a larger ideal body-size has been attributed to experimenters’ failure to discriminate between the desires to lose adipose tissue and gain muscle tissue (McCabe & Ricciardelli, 2004).

An examination of developmental trends in body dissatisfaction has revealed increasing body dissatisfaction with age, particularly among female adolescents (Brodie et al., 1994; Carlson Jones, 2004; Davies et al., 1986; Gardner et al., 1999a; Gardner et al., 1999b; Kostanski et al., 2004; Rosenblum et al., 1999). Females have shown greater discrepancies between perceived and ideal body-sizes at advanced pubertal stages compared with less sexually mature females (Brodie et al., 1994; Cohn et al., 1987).
Males, in contrast, have shown generally stable or decreasing body dissatisfaction through adolescence (Eisenberg et al., 2006; Gardner et al., 1999a; Gardner et al., 1999b; Rosenblum et al., 1999). These differing male and female body-dissatisfaction trends may be explained, in part, by physical changes associated with pubertal development (Koff et al., 1990). For instance, changes inherent to female pubertal maturation (e.g., increased body fat) would result in a body form that deviates from their desired ideal body-size (e.g., thinner), thereby driving a progressive increase in body dissatisfaction. Pubertal changes in males (e.g., increased shoulder width, increased muscle mass) would result in a convergence between the real and ideal male form, potentially leading to stable or decreased levels of body dissatisfaction. The conflicting desires of males to either gain or lose weight may also be explained by an interaction with age as younger and older males have expressed preferences for heavier and leaner ideal body-sizes, respectively (Parkinson et al., 1998).

Body dissatisfaction may also be considered in the context of an individual’s real body-size (e.g., BMI). Among female adolescents, positive correlations have been reported between body dissatisfaction and a subject’s weight:height ratio (Davies et al., 1986) as well as BMI (Kostanski et al., 2004; Kostanski et al., 1998; Rierdan & Koff, 1997; Rosenblum et al., 1999). Males, in contrast, have shown either a positive correlation between body dissatisfaction and subject BMI (Rosenblum et al., 1999) or an interaction between BMI and body dissatisfaction with both underweight and overweight adolescents exhibiting greater body dissatisfaction when compared with normal-weight males (Kostanski et al., 2004). Underweight and overweight males have expressed a desire to gain or lose weight, respectively (Kostanski et al., 2004). The selected male ideal has also differed as a function of subject Tanner stage with larger ideal bodies being
preferred as males become more sexually mature (Cohn et al., 1987)

Other important modulatory factors may include self-esteem, mood, and social interactions. Adolescent body-dissatisfaction has been positively correlated with anxiety and depression and negatively correlated with self-esteem (Koff et al., 1990; Kostanski et al., 1998; Rierdan et al., 1997; Tiggemann et al., 1998). Female sex, high BMI, low self-esteem, depression, and anxiety have all predicted adolescent body-dissatisfaction (Kostanski et al., 1998; Paxton, Eisenberg, & Neumark-Sztainer, 2006; Vander Wal & Thelen, 2000). Body dissatisfaction has also been predicted by conversations with peers about appearance, appearance-driven acceptance by peers, peer teasing, and social comparison (Carlson Jones, 2004; Paxton et al., 2006; Vander Wal et al., 2000).

Although the clinical importance of body-size perceptual biases has been described in the context of eating disorders, body dissatisfaction may also hold significant clinical importance even among otherwise healthy individuals. Lower body satisfaction among children and adolescents has predicted eating problems such as higher levels of dieting, unhealthy weight-control behaviours (e.g., skipping meals, fasting, smoking cigarettes), and binge-eating (Attie & Brooks-Gunn, 1989; Davison, Markey, & Birch, 2003; Neumark-Sztainer, Paxton, Hannan, Haines, & Story, 2006). Similarly, low body-esteem and a smaller ideal body-size among adolescent females have proved to be predictors of higher eating-disorder scores (Gardner et al., 2000).

### 1.7.2 Adult Body-Dissatisfaction

In adults, studies of body dissatisfaction have reported similar sex, age, and BMI effects to those described above in adolescent populations. Adult females have exhibited
greater body dissatisfaction than males, as defined by questionnaire scores or the difference between perceived and ideal body-sizes (Altabe & Thompson, 1993; Aruguete, DeBord, Yates, & Edman, 2005; Dolan et al., 1987; Fallon & Rozin, 1985; Shih & Kubo, 2002). Females have shown a consistent desire for a smaller or thinner ideal body-size (Brodie et al., 1991; Dolan et al., 1987; Fallon et al., 1985; Gardner et al., 1999c; Garfinkel et al., 1979; Garfinkel et al., 1978; Garner et al., 1976; Probst et al., 1992; Sands et al., 2004; Schlundt et al., 1993; Shih et al., 2002; Tovee et al., 2003) while males have reported a desire for both smaller/leaner or larger/more muscular ideal body-sizes (Brodie et al., 1991; Dolan et al., 1987; Gardner et al., 1999c; Kagawa et al., 2006; Pope, Jr. et al., 2000). Levels of body dissatisfaction have correlated positively with age (Altabe et al., 1993). Finally, an analysis of subject BMI revealed that, among females, a high BMI may be associated with a desire for a thinner ideal body-size (Tovee et al., 2003).

1.8 Relationship between Self Body-Size Perception and Body Dissatisfaction

Although numerous studies have examined body-size perception and body dissatisfaction independently, few have attempted to assess the relationship between these two important components of body image. In the few existing studies, a significant negative correlation has been identified between estimates of self body-size and body satisfaction (Garner et al., 1981). Furthermore, indices of perceived body-size have been positively correlated with EAT-26 and EDI scores (Gila et al., 2005; Sunday et al., 1992), as well as negatively correlated with EDI scores (Pumariega et al., 1993; Whitehouse et al., 1988). In contrast, other studies have observed little or no relationship between indices of body-size estimation and body dissatisfaction (Shafran et al., 2002; Thompson
1.9 Body Perception and the Brain

Thus far, we have reviewed: (1) various behavioural methods used to assess body image and (2) behavioural findings related to the existence of perceptual biases in body-size estimation among adolescents and adults. As part of the thesis objectives, we intend to explore the neural mechanisms underlying human body-perception. We hope to identify the neural substrates of potential sex and BMI effects identified in the behavioural assessment of self body-size estimation. In the following sections, we will review: (1) disorders of human body-representation, (2) neural substrates of body representation in nonhuman primates, and (3) neural substrates of body representation in humans.

1.9.1 Disorders of Human Body-Representation

In the late nineteenth and throughout the twentieth century, a large number of case studies described patients suffering from different types of disorders of body representation. The most common disorders involve deficits in body-part localization (Buxbaum & Coslett, 2001; De Renzi & Scotti, 1970; Denes, Cappelletti, Zilli, Porta, & Gallana, 2000; Felician, Ceccaldi, Didic, Thinus-Blanc, & Poncet, 2003; Guariglia, Piccardi, Puglisi Allegra, & Traballesi, 2002; Ogden, 1985; Semenza, 1988; Semenza & Goodglass, 1985; Sirigu et al., 1991), deficits in producing or understanding body-part names (Dennis, 1976; Laiacona, Allamano, Lorenzi, & Capitani, 2006; Suzuki, Yamadori, & Fujii, 1997), abnormal perception of body or body-part size (Kew et al., 1988).
and out-of-body experiences (Blanke, Landis, Spinelli, & Seeck, 2004; Devinsky, Feldmann, Burrowes, & Bromfield, 1989; Lippman, 1953). These deficits were associated most commonly with lesions in the parietal and temporal lobes (Blanke et al., 2004; De Renzi et al., 1970; Ogden, 1985). This will be discussed in greater detail below.

The ability to localize body parts, whether of self and/or others, has been debated widely, starting with Pick's seminal descriptions of two patients suffering from an inability to point to their own body parts while retaining the ability to name them, leading Pick to term this disorder autotopagnosia (Pick, 1922). Later descriptions of patients whose "body" localization deficits extended to the bodies of others led to the suggestion that this syndrome may be more generalized and should be described as somatotopagnosia (Gerstmann, 1942). Over the years, the accumulation of further case studies has generated a broader definition of autotopagnosia that encompasses an inability to localize body parts on one's own body, the body of another, or even on a picture of a body in response to verbal and/or nonverbal commands (Buxbaum et al., 2001; De Renzi et al., 1970; Denes et al., 2000; Felician et al., 2003; Guariglia et al., 2002; Ogden, 1985; Schwoebel, Branch Coslett, & Buxbaum, 2001; Semenza, 1988; Semenza et al., 1985; Sirigu et al., 1991). The neural substrate of these deficits remains broadly described since many of the patients often show generalized damage including diffuse cerebral atrophy (Schwoebel et al., 2001; Sirigu et al., 1991) or damage involving multiple brain regions (Buxbaum et al., 2001; Schwoebel et al., 2001). Nevertheless, most cases suggest that damage in the left parietal and temporal lobes may underlie the deficits in autotopagnosia (De Renzi et al., 1970; Denes et al., 2000; Felician et al., 2003; Ogden, 1985; Semenza, 1988).
The pattern of deficits in autotopagnosia has provided some insight into: (1) the body-related specificity of the disorder and (2) the potential for multiple body-representations in the brain. In describing the body-related deficits in autotopagnosia, the question has been raised as to whether these deficits are specific to the human body or may simply reflect a wider deficit in the ability to analyse a whole into its constituent parts (De Renzi & Faglioni, 1963; De Renzi et al., 1970). The latter does not appear to be the case: many patients have demonstrated deficits in self body-part localization while retaining the ability to identify parts of other living and nonliving objects (Denes et al., 2000; Guariglia et al., 2002; Ogden, 1985; Semenza, 1988; Sirigu et al., 1991). These findings are, therefore, indicative of a neural system specifically devoted to body representation in humans (Guariglia et al., 2002; Semenza, 1988; Sirigu et al., 1991).

In fact, lesion studies have supported the idea of *multiple* body-representations in the brain; some patients with autotopagnosia have reported deficits in the localization of body parts in the absence of any semantic or lexical deficits (e.g., naming) or deficits in identifying the function of body parts, thereby indicating a potential dissociation between body structural and lexical-semantic representations of the body, consistent with Sirigu’s multiple representational model (Buxbaum et al., 2001; De Renzi et al., 1970; Denes et al., 2000; Felician et al., 2003; Guariglia et al., 2002; Ogden, 1985; Sirigu et al., 1991). Patients have also reported selective sparing of semantic body knowledge associated with autotopagnosia, as well as independent deficits in body knowledge irrespective of autotopagnosia; these independent semantic deficits have been associated with temporal lobe damage (Coslett, Saffran, & Schwoebel, 2002; Dennis, 1976; Laiacona et al., 2006; Suzuki et al., 1997). This has also been confirmed by a study examining a large stroke population which revealed that lesions of the left temporal lobe were consistently
associated with deficits in shape and/or lexical-semantic body knowledge while lesions of the dorsolateral frontal and parietal cortex were associated with impairments in the encoding of body posture (Schwoebel & Coslett, 2005). Finally, some patients with autotopagnosia showed a selective deficit in localizing their own body parts but not of others (and vice versa), indicating the potential for separate representations of one’s own body versus those of others (Felician et al., 2003). As indicated by these findings, autotopagnosia may reflect impairment in the visuospatial processing of body shape and contours as well as the local relationship between body parts, whether of one’s own body or that of another (Buxbaum et al., 2001; Guariglia et al., 2002; Sirigu et al., 1991). Moreover, the pattern of dissociated deficits offers insight into the potential for multiple representations of the human body involving body structure, body semantics, and even body agency.

A number of studies examining out-of-body experiences (OBEs) have also offered some insight into the neuroanatomical substrates of the human body. Out-of-body experiences are characterized by three main phenomena: (1) disembodiment, (2) the experience of viewing the environment from a distant and elevated visuospatial perspective, and (3) the experience of viewing one’s body from this perspective (Blanke & Arzy, 2005). Out-of-body experiences have been observed often in the context of epilepsy and migraine (Blanke et al., 2004; Devinsky et al., 1989; Lippman, 1953).

Epileptic foci and lesions have been examined extensively in an effort to identify an underlying anatomical substrate for OBEs. Various electroencephalographic (EEG) and neuroimaging studies have generally reported seizure foci and/or lesion damage in the temporal and parietal lobes of OBE patients (Daly, 1958; Devinsky et al., 1989; Lunn, 1970). In a more recent study, Blanke and colleagues performed a lesion analysis of OBE
patients and reported a mean lesion overlap centred at the temporo-parietal junction (TPJ), which included the angular gyrus and superior temporal gyrus (Blanke et al., 2004). The proposed involvement of the TPJ was corroborated by a study describing the effect of electrical stimulation of the angular gyrus in a patient with epilepsy; the stimulation induced an OBE as well as vestibular and complex somatosensory responses, the latter of which included illusions such as the perceived shortening of the patient’s legs and arms (Blanke et al., 2002).

The temporo-parietal junction may be involved in the integration of proprioceptive, tactile, vestibular, and visual information to generate a central representation of the body (Blanke et al., 2005). Thus, input from these various sensory sources are assessed and integrated, at least in part, by the TPJ into a coherent body-representation reflecting the movement and position of the body, as well as its position in the external environment (Blanke et al., 2005). Damage to the TPJ, as seen in many patients with OBEs, may result in a failed integration and an incoherent body-representation in which one may “see” the body in a position inconsistent with the “felt” position of the body (Blanke et al., 2005).

Although case studies such as those described above do offer insight into the neural correlates of body representation, these patients do not typically report symptoms directly related to the perception of body size and shape. Microsomatognosia and macrosomatognosia, in contrast, refer to two body disorders in which patients perceive their bodies or body parts as abnormally small or large, respectively (Frederiks, 1963). Reports have described both disorders as components of migraine and epilepsy, whereby epileptiform activity in the parietal and occipital lobes has been associated with a perceived shrinking of body-part size (Kew et al., 1998; Leker et al., 1996; Podoll et al., 2000; Salanova, Andermann, Rasmussen, Olivier, & Quesney, 1995; Todd, 1955).
In summary, clinical data, derived from the examination of various body-image disorders, have implicated the parietal and temporal lobes as potential neuroanatomical substrates of body representation. These regions may be involved in \textit{multiple components} of body representation including semantic body knowledge, visuospatial representation of body parts, or even a sense of body agency. These clinical case studies, however, are limited in their ability to identify the precise mechanisms by which these regions may act in the generation of a holistic perspective of one's own body or that of another. Patients with these body disorders are quite rare and are often diagnosed with multiple disorders, some of which involve neurological and/or psychiatric symptoms. Although these case studies are a useful foundation from which to derive \textit{broad} anatomical correlates of body representation and the perception of size and shape, there is a substantial need for corroborating evidence derived from studies of animal models and healthy participants.

\subsection*{1.9.2 Neural Correlates of Body Perception in Nonhuman Primates}

Regions in the macaque inferior temporal (IT) cortex and superior temporal sulcus (STS) have shown selective responses to images of whole bodies and/or individual body parts, as evidenced by single cell recording (Desimone, Albright, Gross, & Bruce, 1984; Gross, Bender, & Rocha-Miranda, 1969; Gross, Rocha-Miranda, & Bender, 1972; Jellema & Perrett, 2003b; Kiani, Esteky, Mirpour, & Tanaka, 2007; Wachsmuth, Oram, & Perrett, 1994) and fMRI studies (Pinsk, DeSimone, Moore, Gross, & Kastner, 2005; Tsao, Freiwald, Knutsen, Mandeville, & Tootell, 2003). Single cell recordings in macaque IT cortex revealed neurons that were selectively responsive to the shape of a hand, whereby stronger responses were observed with: (1) upright (e.g., fingers pointed
upward) or lateral hand positions and (2) greater stimulus similarity to a defined hand shape with fingers being a critical feature (Desimone et al., 1984; Gross et al., 1969; Gross et al., 1972). Most importantly, body-selective IT neurons failed to respond to other complex stimuli or faces (Desimone et al., 1984). Further investigation showed that macaque IT neurons demonstrate highly selective responses for body parts including monkey and human hands, responses that are invariant to visual field position, hand size, and orientation (Desimone et al., 1984).

A recent study examined the responses of more than 600 neurons in monkey IT cortex upon presentation of more than 1000 images of natural and artificial objects including bodies of humans, four-limbed animals, reptiles, and insects (Kiani et al., 2007). An analysis of activity patterns distributed across the cell population revealed distinguishable clusters of activity for animate (e.g., faces, bodies, hands) versus inanimate objects. Furthermore, distinct patterns of response could be identified for faces versus bodies. Even subdivisions of the body category showed a clustered response pattern with human bodies, birds, and four-limb animals forming one cluster and fish, reptiles, and insects forming another. Single-cell recordings from the same study revealed that some cells did show selective responses for a single category of stimuli (e.g., human bodies versus four-limb animal bodies); other cells responded to a combination of categories. Partial selectivity on the part of individual cells may be compensated for by averaging responses over a small population of cells, thereby generating a cluster with strong category selectivity.

Similar electrophysiological findings have been reported for neurons located in the upper and lower bank of the anterior STS, as cells have been identified with strong selectivity for multiple human body-parts (e.g., torso and limbs) or the whole human body.
(Barraclough, Xiao, Oram, & Perrett, 2006; Wachsmuth et al., 1994). Moreover, STS responses to the whole body were found to be view-dependent (Wachsmuth et al., 1994). These single-cell recording results have been corroborated by recent studies using fMRI in macaques; anterior and posterior body-selective regions were identified along the banks and fundus of the STS (Pinsk et al., 2005; Tsao et al., 2003). Both the anterior and posterior STS body regions responded with greater strength during the presentation of body parts compared with objects and faces (Pinsk et al., 2005). Both regions, and in particular the anterior one, were localized adjacent to or overlapping partially with face-selective regions (Pinsk et al., 2005; Tsao et al., 2003). The response of the anterior STS body region was more robust and reliable when compared with the posterior STS body region (Pinsk et al., 2005). Neurons located in the anterior STS may also encode body actions and the consequent articulated static body-postures (Barraclough et al., 2006; Jellema & Perrett, 2003a; Oram & Perrett, 1996; Perrett et al., 1985). In fact, anterior STS neurons’ response to body postures may be dependent on the particular body action directly preceding it (Jellema et al., 2003b).

1.9.3 Neural Correlates of Body Perception in Humans

Over the past decade, tremendous strides have been made in identifying and characterizing the neuroanatomical substrates of body perception in humans. Studies have localized regions that show selective brain responses to images of human bodies and identified the precise body characteristics for which these regions may be responsible (e.g., body structure, body agency). Clinical studies have clearly implicated the parietal and temporal lobes as integral to our understanding of the human body. Furthermore,
nonhuman primate studies have focused our attention on such regions as the IT cortex and STS as potential areas of interest. We will now review the existing literature as it pertains to the visual perception of the human body by human primates.

1.9.4 Specialized Processing of Human Bodies: Behavioural Studies

Human bodies, like human faces, have often been described as biological objects for which specialized neural processing may be expected. For example, a reliable face-inversion effect has been reported, whereby human participants showed impaired object recognition for inverted faces compared with upright faces (Valentine, 1988; Yin, 1969). This face-inversion effect has been used as evidence of configural processing of face images (Farah, Tanaka, & Drain, 1995; Valentine, 1988; Yin, 1969). A similar body-inversion effect has been observed (i.e., impaired recognition for inverted bodies); no performance effect was reported for control object-stimuli including houses (Reed, Stone, Bozova, & Tanaka, 2003). This body-inversion effect was also specific to intact whole and half-body postures (versus body parts) with proper spatial relations between body parts (Reed, Stone, Grubb, & McGoldrick, 2006). This body-inversion effect has been used as evidence of configural processing of body images, whereby bodies are perceived using specific spatial relations between body features as opposed to the presence or absence of individual body-parts (Reed et al., 2003; Reed et al., 2006).

Further evidence of specialized body processing may be derived from attention studies in which body stick-figures and silhouettes captured the attention of human participants preferentially compared with intact or scrambled object-stimuli as well as hand stimuli (Downing, Bray, Rogers, & Childs, 2004; Mack & Rock, 1998). Enhanced
detection of body silhouettes and stick figures was reported when such figures were presented to subjects without warning while they were performing a line judgment task (Downing et al., 2004; Mack et al., 1998). These findings are consistent with the enhanced detection rates observed for face stimuli (Mack et al., 1998). Based upon these findings, human bodies may be considered a prioritized category of stimuli for the attention system (Downing et al., 2004).

1.9.5 Electrophysiological Studies of Human Body-Perception

Event related potential (ERP) studies have revealed specific electrophysiological responses to human bodies that are distinct from face-specific responses (Gliga & Dehaene-Lambertz, 2005; Thierry et al., 2006). In adults, presentation of human bodies revealed a strong N1 component, localized over occipito-temporal regions, peaking at 228 ms that was: (1) significantly larger than the N1 component elicited by scrambled images and (2) significantly delayed compared with the face-related N1 component (Gliga et al., 2005).

Further exploration of body-related ERPs has revealed a specific negative component peaking at 190 ms (N190) following body presentation, which differed in both spatial distribution and amplitude from the face-specific N170 component (Thierry et al., 2006). Localization analysis revealed sources in the right posterior extrastriate cortex (Thierry et al., 2006). In support of the behavioural inversion and ERP findings, inversion of bodies was associated with enhanced amplitudes and a significant delay in the N170 component; no significant differences were detected between faces and bodies (Stekelenburg & de Gelder, 2004).
1.9.6 Perception of Static Human Body-Images: Extrastriate Body Area (EBA) and Fusiform Body Area (FBA)

In accordance with the occipitotemporal and extrastriate findings of the aforementioned ERP studies, fMRI studies have recently identified two regions that show greater responses to still images of human bodies and body parts when compared with inanimate objects or object parts: the extrastriate body area (EBA) located in the lateral occipitotemporal cortex (Downing, Chan, Peelen, Dodds, & Kanwisher, 2006a; Downing, Jiang, Shuman, & Kanwisher, 2001; Downing, Wiggett, & Peelen, 2007; Spiridon, Fischl, & Kanwisher, 2006; Taylor, Wiggett, & Downing, 2007) and the fusiform body area (FBA) located in the lateral posterior fusiform gyrus (Peelen & Downing, 2005a; Schwarzlose, Baker, & Kanwisher, 2005; Taylor et al., 2007). Extrastriate body area and FBA have shown great reliability and specificity in their response to human bodies. For example, robust localization of EBA has been reported within and across scanning sessions conducted over three weeks (Peelen & Downing, 2005b). Moreover, high EBA selectivity for human bodies and body parts has been demonstrated irrespective of presentation format including photographs, line drawings, stick figures, or human silhouettes (Downing et al., 2001).

Most importantly, EBA has demonstrated particular specificity for human bodies relative to other object stimuli. Greater EBA response has been detected for human bodies compared with human body-parts, as well as with a large variety of control stimuli including mammals, insects, flowers, tools, and cars (Downing et al., 2006a; Downing et al., 2001). In addition, a greater EBA response has been detected for nonhuman mammals compared with objects (Downing et al., 2006a; Downing et al., 2001). It has been concluded that EBA shows maximal specificity for human bodies with a potential modest
preference for nonhuman mammals (Downing et al., 2001). Extrastriate body area has also demonstrated a greater response to human bodies compared with objects composed of constituent subparts connected at flexible joints (e.g., scissors), indicating that EBA responds specifically to the body form (Downing et al., 2001).

The specificity of EBA for human bodies has been corroborated by direct intracranial recording of body-selective responses in the human extrastriate cortex (Pourtois, Peelen, Spinelli, Seeck, & Vuilleumier, 2007). Recordings from a single subdural electrode located in the extrastriate visual cortex of a patient with epilepsy revealed a highly selective response to bodies compared with faces, tools, and mammals, starting at approximately 190 ms and peaking at 260 ms poststimulus onset (Pourtois et al., 2007). Localization of the electrode was consistent with EBA, as reported in previous fMRI studies (Pourtois et al., 2007).

The specificity of FBA for human bodies has been investigated to a much lesser extent. Nonetheless, several fMRI studies have reported greater FBA response to faces and bodies compared with cars, tools, and scenes; FBA failed to distinguish between faces and bodies (Peelen et al., 2005a; Schwarzlose et al., 2005). Fusiform body area, localized in an fMRI experiment conducted at higher resolution, did show greater selectivity, whereby the response for headless body-stimuli was greater than faces (Schwarzlose et al., 2005). Nonetheless, FBA still showed a preferential response for faces compared with mixed objects (Schwarzlose et al., 2005).

The selectivity of EBA and FBA may not be absolute, as indicated by the findings of: (1) some degree of functional overlap between EBA and other regions including the lateral occipital cortex (LOC), the parahippocampal place area (PPA), and visual motion area MT/V5 (Downing et al., 2001; Downing et al., 2007; Spiridon et al., 2006), as well
as between FFA and FBA (Peelen et al., 2005a; Schwarzlose et al., 2005); (2) EBA and FBA responses to face stimuli above and beyond that of object stimuli (Downing et al., 2001; Peelen et al., 2005a; Schwarzlose et al., 2005); and (3) responses by FFA and area MT/V5 upon presentation of body images (Downing et al., 2006a; Peelen et al., 2005a; Saxe, Jamal, & Powell, 2006; Spiridon et al., 2006). The relative overlap across several functional regions may indicate that they share in a computational process that is required by the different stimuli (Downing et al., 2007). In some cases, this apparent overlap may also be the result of low spatial resolution (Schwarzlose et al., 2005).

Nevertheless, there is growing evidence that EBA and FBA may respond specifically to human bodies since: (1) researchers have identified consistently voxels that show a unique response in EBA and not in area MT/V5 or LOC (Downing et al., 2001); (2) voxel-wise correlations between t-statistic maps representing visual motion, object form, and human body-form selectivity revealed relatively independent patterns of fMRI activity (Downing et al., 2007; Peelen & Downing, 2006); (3) calculation of distances between FBA and FFA within subjects revealed distinct peaks of activation for bodies and faces (Peelen et al., 2005a); and (4) use of high-resolution fMRI (e.g., voxel size: 1.4 x 1.4 x 2.0 mm) and analysis of refined regions of FFA and FBA, containing no overlapping voxels, revealed highly selective responses, respectively, for faces and bodies only (Schwarzlose et al., 2005). Thus, reports of dual selectivity of FFA and FBA for faces and bodies may be the potential result of pooling responses from two adjacent, yet distinct, cortical regions (Schwarzlose et al., 2005). An FFA response to the presentation of a headless body may also be due to subjects’ imagining of a face to accompany the body (Spiridon et al., 2006). Extrastriate body area and FBA may, therefore, represent distinct functional regions that lie in close physical proximity to other object-selective
regions but remain selectively responsive to bodies and body parts (Schwarzlose et al., 2005).

With the identification of two body-responsive regions, EBA and FBA, the question remains as to whether these regions process body images independently or in concert, as well as whether they process identical or different aspects of bodies. In order to map the functional profiles of EBA and FBA, Taylor and colleagues measured the magnitude of fMRI response as a function of the amount of a human body presented, ranging from a single digit to a whole body (Taylor et al., 2007). They reported that the EBA response rose gradually in a linear fashion as a function of the proportion of body visible to the subject. In contrast, FBA showed no distinct selectivity for fingers or hands but a step-like increase in response with the appearance of whole torsos. Such responses were exclusive to the presentation of bodies and were not observed with other compartmentalized object-stimuli such as trees. Based upon these results, it has been proposed that EBA and FBA show representational biases towards individual body-parts and larger body portions, respectively. The stated preference of EBA for body parts should be interpreted in the context of the larger response found for EBA to whole bodies compared with body parts (Downing et al., 2001); the greater EBA response to whole bodies may be due to the fact that there are a greater number of body parts present in the whole body-image (Downing et al., 2007). The reported strong selectivity of FBA for torsos and arms supports the likelihood that FBA preferentially represents larger segments of the body and contributes to the processing of body parts into a whole-body configuration (Taylor et al., 2007).

Thus far, we have described brain responses to the simple visual presentation of isolated static bodies and body parts. But bodies are rarely experienced in a completely
static form without any external context including other bodies or objects. In order to address this issue, an effort has been made to assess the neural substrates of body perception when viewing bodies in a more natural environment such as in a movie that includes background scenery, faces, and motion (Bartels & Zeki, 2004). Subjects were asked to rate the intensity with which they perceived various stimuli (e.g., faces, colour, human bodies) during the presentation of a motion picture (Bartels et al., 2004). Ratings of human bodies correlated bilaterally with responses in EBA and a region in the anterior lateral fusiform gyrus (Bartels et al., 2004). Thus, EBA and FBA may play a role in the processing of relatively simple visual presentations of bodies and body parts, as well as bodies in the context of complex visual scenes.

Although many studies have reported a bilateral response to images of human bodies, hemispheric differences in body processing have been described. In a broad context, ERP research has revealed that presentation of body images to adult subjects may be associated with a significantly greater right occipito-temporal N1 response compared with the left hemisphere (Gliga et al., 2005). In the same study, the distortion of body images had a more pronounced effect on the right versus left N1 response (Gliga et al., 2005).

Right EBA may be more selective for human bodies compared with left EBA since: (1) right EBA is often localized with greater consistency (Downing et al., 2001); (2) right EBA shows a distinctly greater response to human bodies compared with the bodies of nonhuman mammals, whereas left EBA shows no such difference (Downing et al., 2006a); and (3) a greater right versus left EBA response has been detected upon presentation of whole bodies (Uher et al., 2005). Distinct patterns of selectivity have been displayed by EBA and FBA as it pertains to individual body-parts and larger body
segments, respectively (Taylor et al., 2007). Additional analyses, however, have also revealed a trend towards a difference between left and right EBA in their linear response to the presentation of increasing number of body parts; there may exist a difference in the "steepness" of the BOLD response as opposed to a qualitative difference (Taylor et al., 2007). This finding may speak to a difference between left and right EBA in their relative sensitivity to individual body-parts (Taylor et al., 2007).

In many of the above studies, simple static bodies were presented while subjects performed a task that did not require subjects to make explicit judgments about the size and shape of bodies or to compare the body images with their own body. For example, many of the localization studies used a "one-back" memory task in which subjects were required to indicate when two identical images were presented consecutively (Downing et al., 2001; Peelen et al., 2005b; Schwarzlose et al., 2005; Spiridon et al., 2006; Taylor et al., 2007). Nevertheless, there is a great deal of experimental and clinical interest in identifying brain regions that show a response while subjects make explicit judgments about the size and shape of body images.

In one such study, healthy subjects and patients with an eating disorder were asked to indicate the "acceptability" of underweight, normal, and overweight bodies (Uher et al., 2005). In response to all three types of bodies, both healthy subjects and patients showed significant responses in EBA, inferior parietal cortex, and lateral prefrontal cortex (Uher et al., 2005). When comparing healthy women and women with an eating disorder, weaker responses were detected in EBA and the parietal cortex of patients compared with healthy women (Uher et al., 2005). In the right fusiform gyrus, patients demonstrated a stronger response compared with controls during presentation of underweight body-images, whereas control subjects showed a stronger response with overweight body-
shapes (Uher et al., 2005). In another study, when asked to compare their own body with slim, idealized, female body-images, healthy women showed significant responses in the bilateral occipitotemporal cortex (including EBA), the right inferior parietal lobule, right lateral prefrontal cortex, and the left anterior cingulate (Friederich et al., 2007). From these results, it is clear that the presentation of body images and, most importantly, making judgments about these body images induce neural responses in EBA and/or FBA and a set of other regions. The pathology of eating disorders may also be associated with reduced responses in EBA.

The question must also be raised as to whether presentation of distorted “self” images versus “other” bodies would make a significant difference in the neural response. In order to explore this question, healthy men and women were presented with pairs of “self” body-images consisting of a real body-image and a distorted body-image of larger or smaller size, and then asked to indicate which body image was perceived as more unpleasant (Kurosaki, Shirao, Yamashita, Okamoto, & Yamawaki, 2006). Healthy women showed significant responses in the prefrontal cortex, amygdala, cerebellum, and cingulate gyrus (Kurosaki et al., 2006). Men, in contrast, demonstrated activity in the primary and secondary visual cortices, temporal lobe, parietal lobe, and cerebellum (Kurosaki et al., 2006). When confronted with their own body image, female patients with anorexia nervosa also showed a strong response in the amygdala, brainstem, and fusiform gyrus (Seeger, Braus, Ruf, Goldberger, & Schmidt, 2002).

1.9.7 Functional Significance of EBA and FBA

Clearly, EBA and FBA are responsive to static images of the human body whether
presented in isolation or in the context of a complex scene. But are EBA and FBA necessary for the processing of static body-images? Repetitive transcranial magnetic stimulation (rTMS) has been used to address the potential causal link between EBA, FBA, and the visual perception of body images. Repetitive transcranial magnetic stimulation of EBA has been already associated with impaired performance in a match-to-sample task involving body parts; application of rTMS over right EBA delayed reaction time when matching body parts, but not noncorporeal stimuli (i.e., motorcycle parts) or face parts (Urgesi, Berlucchi, & Aglioti, 2004). A subsequent study investigated the functional role of right EBA, left ventral premotor cortex (vPMc), right superior parietal lobe (SPL), and right V1 in the local processing of inverted bodies or configural processing of upright bodies (Urgesi, Calvo-Merino, Haggard, & Aglioti, 2007a). Matching of inverted body-images (but not of upright body-images) was significantly impaired following rTMS of right EBA compared with stimulation of vPMc, SPL, or V1 (Urgesi et al., 2007a). In addition, an increase in the body-inversion effect was observed following rTMS of EBA compared with stimulation of SPL and vPMc (Urgesi et al., 2007a). Repetitive transcranial magnetic stimulation applied over vPMc impaired matching of upright body-postures and reduced the body-inversion effect (Urgesi et al., 2007a). The role of EBA in the recognition of body identity has also been explored using rTMS; stimulation of EBA and vPMc impaired discrimination of body forms and body actions, respectively (Urgesi, Candidi, Ionta, & Aglioti, 2007b).

Overall, Urgesi and colleagues have proposed that two potential pathways may contribute to the processing of human bodies: (1) a configural processing pathway involving the vPMc by which a sense of embodiment may be established through sensorimotor representations and (2) a local processing pathway involving EBA by which
local features such as body parts and body form are encoded (Urgesi et al., 2007a). This proposed relationship between EBA and the local processing of individual body-parts and body form is consistent with Taylor and colleagues’ work using fMRI (Taylor et al., 2007).

1.9.8 EBA, FBA, and Biological Motion

To date, a number of human studies have described brain regions that show a strong response to the biological motion (BM) of full bodies or body parts. These regions include both visual and nonvisual areas such as the: (1) STS (Beauchamp, Lee, Haxby, & Martin, 2003; Bonda, Petrides, Ostry, & Evans, 1996; Grossman et al., 2000; Grossman, Battelli, & Pascual-Leone, 2005; Grossman, Blake, & Kim, 2004; Peelen, Wiggett, & Downing, 2006; Pelphrey et al., 2003; Peuskens, Vanrie, Verfaillie, & Orban, 2005; Puce, Allison, Bentin, Gore, & McCarthy, 1998; Vaina, Solomon, Chowdhury, Sinha, & Belliveau, 2001; Wheaton, Thompson, Syngeniotis, Abbott, & Puce, 2004); (2) parietal cortex (Bonda et al., 1996; Buccino et al., 2001; Wheaton et al., 2004); (3) inferior frontal gyrus as the human homologue of monkey area F5 in the premotor cortex (Vaina et al., 2001); (4) area MT/V5 (Howard et al., 1996; Peelen et al., 2006; Peuskens et al., 2005; Puce et al., 1998; Vaina et al., 2001; Wheaton et al., 2004); (5) premotor cortex (Buccino et al., 2001; Wheaton et al., 2004); (6) occipital and fusiform face areas (Grossman & Blake, 2002; Grossman et al., 2004; Peelen et al., 2006); (7) lingual gyrus (Vaina et al., 2001); (8) amygdala (Bonda et al., 1996); and (9) cerebellum (Grossman et al., 2000; Vaina et al., 2001). Much of the research has focused on a set of regions along the STS as regions that are particularly selective to BM whether it be point-light motion displays of
body parts (e.g., hand) or the whole body (Beauchamp et al., 2003; Bonda et al., 1996; Grossman et al., 2000; Grossman et al., 2002; Johansson, 1973; Peelen et al., 2006; Vaina et al., 2001) or videos of whole-body movements (Beauchamp et al., 2003), eye and mouth movements (Puce et al., 1998), or face, hand, and leg movements (Wheaton et al., 2004). The STS response to BM has been described as right hemisphere dominant (Beauchamp et al., 2003; Grossman et al., 2000; Pelphrey et al., 2003; Peuskens et al., 2005; Puce et al., 1998; Wheaton et al., 2004), as well as particularly selective for biological motion, irrespective of the figure form or surface features of the stimulus performing the motion (Pelphrey et al., 2003; Peuskens et al., 2005). Similar STS responses have been observed during the presentation of BM performed by humans or a robot; yet, these responses were still significantly greater than those elicited by complex, meaningless, nonbiological motion or complex, coherent, meaningful, nonbiological motion (Pelphrey et al., 2003). Similarly, STS has shown a relatively strong response to BM compared with the 3D rotation of a figure or an articulated motion (Peuskens et al., 2005). In contrast to this BM selectivity for STS, area MT/V5 has responded equally to BM, 3D rotation, articulated motion, and inverted BM, leading to the hypothesis that MT/V5 responds preferentially to motion rather than the figure or action involved (Peuskens et al., 2005).

Although a large number of regions have been identified, their function has often been viewed in the context of a hierarchical pathway model that defines dorsal “spatial” and ventral “object” pathways (Livingstone & Hubel, 1987; Ungerleider & Mishkin, 1982). It has been hypothesized that the dorsal pathway, involving the dorsal aspects of the extrastriate and posterior parietal areas, may be responsible for the encoding of information about object location and movement while the ventral pathway may be
involved in the encoding of shape and identity information (Livingstone et al., 1987; Ungerleider et al., 1982). A complementary hierarchical model has been recently proposed that suggests the existence of two parallel processing streams, analogous to the dorsal and ventral pathways, that encode information about optic flow and form, respectively (Giese & Poggio, 2003). According to this model, the representation of BM is achieved through the encoding of sequences of “snapshots” of both body shapes in the form pathway and sequences of optic-flow patterns in the motion pathway, with ultimate integration of the information from both pathways in regions located along the STS (Giese et al., 2003; Peuskens et al., 2005).

Given this emphasis on body form and shape in the detection of BM and the identification of EBA and FBA as body-responsive brain regions, there has been growing interest in exploring whether these functional areas play a role, if any, in the perception of BM. Downing and colleagues asked whether EBA responds to: (1) the human form in a “static” representation of BM or (2) the biological actions of bodies in a “dynamic” representation of BM, thereby indicating that EBA may play some role in the mirror neuron system (Downing, Peelen, Wiggett, & Tew, 2006b). Previous fMRI studies have demonstrated that bilateral EBA and right FBA do show a significant response to point-light animations of BM when compared with scrambled stimuli (Downing et al., 2001; Michels, Lappe, & Vaina, 2005; Peelen et al., 2006). In direct contrast, no significant difference in EBA response has been observed with biological point-light animations compared with scrambled stimuli (Grossman et al., 2002). In an effort to characterize the precise components of BM to which EBA and FBA may be responsive, voxel-by-voxel correlations have been reported between biological motion-selectivity with body-selectivity in EBA and FBA, but not with motion-selectivity in area MT/V5 or face
selectivity in FFA, as defined by calculated t-values for each voxel (Peelen et al., 2006). The results indicated that biological motion-selectivity was significantly correlated with body-selectivity only (Peelen et al., 2006). The authors speculated that EBA and FBA may contribute to the detection of BM through the processing of body form as part of the ventral “form” pathway, as opposed to changes in body posture/movement (Peelen et al., 2006).

Additional fMRI and TMS studies have provided evidence consistent with this proposed role for EBA and FBA as processing sites of body form and shape. For example, Downing and colleagues recently concluded that EBA computes a static representation of the human body rather than analysing biological motion, as evidenced by a decreased EBA response (i.e., fMR-adaptation) to body images of similar body configuration (Downing et al., 2006b). EBA has also responded preferentially to point-light animations that have been modified to provide greater form information compared with classic point-light animations (Michels et al., 2005). Finally, rTMS of EBA and vPMc was associated with selective impairment in the discrimination of body forms and actions, respectively (Urgesi et al., 2007b). Consequently, the data suggest that EBA and FBA are involved in the processing of body form and shape, rather than the dynamic aspects of BM.
Chapter 2

Assessment of Adolescent Body-Perception: Development and Characterization of a Novel Tool for Morphing Images of Adolescent Bodies

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Behavior Research Methods (2007)
39(3): 651-666
2.1 Preface

As described in the literature review, numerous methodologies have been developed and implemented in studies examining the visual perception of body size and shape. Many of these studies, however, are limited by the physical apparatuses, visual stimuli, or psychophysical methods used. It is our belief that the body-image stimuli and the process of image distortion used in many of these studies represent a fundamental methodological limitation. For example, mock silhouette or body figures, which are used extensively in the field, are limited by scale coarseness, unequal and unquantifiable changes in body size and shape, and their inability to account for ethnic differences. Furthermore, techniques that make use of television and video-based distortions typically utilize linear global distortions that stretch or shrink body parts universally across all body parts, thereby creating highly unrealistic body-images. Even with the latest incarnation of computer-based algorithmic methods, the mathematical models often fail to account for natural covariations between body parts in the body-distortion process. To our knowledge, there exists no mathematical model specifically devoted to the characterization of adolescent-based changes in body size and shape and consequently, no tool specifically devoted to generating realistic morphed body-images of adolescents.

In order to properly investigate adolescent perception of body size and shape, we must first address this methodological void. It is our belief that any rigorous assessment of adolescent body-perception must involve the use of adolescent body-images morphed using an adolescent-derived model of adolescent changes in body size and shape. Chapter 2 describes the development and characterization of a novel adolescent body-morphing
tool that may be used to generate realistic morphed body-images of adolescents, which respect the natural covariations between body parts.
2.2 Abstract

We developed a computer-based method of distorting adolescent body-images, which incorporates the covariation between body parts found during growth and sexual maturation. An Adolescent Body-Shape Database (AdoBSD) and Adolescent Body-Morphing Tool (AdoBMT) are described; the AdoBSD is comprised of real (n = 320) and morphed (n ≈ 41,000) images (front and side view) of 160 adolescents (9 to 17 years). We used a point distribution model, based upon principal components analysis, to characterize the covariation between predefined body tag-points manually positioned on the body images and to morph the body images in a realistic manner. Eight principal components (PCs) were found to characterize 96.3% of the covariation between body tag-points. Application of the PCs to the body images resulted in the manipulation of body parts including shoulder width, waist, hip, belly, thigh, and calf sizes. The AdoBMT and AdoBSD may be used to investigate changes in body perception during adolescence and the role of body perception in adolescent obesity and eating disorders. The AdoBSD is available to the research community (www.brainbody.nottingham.ac.uk).
2.3 Introduction

Body image has been described as “the picture we have in our minds of the size, shape and form of our bodies; and to our feelings concerning the size, shape and form of our bodies, and its constituent body parts” (Slade, 1988; p.20). This definition encompasses two key components that have been identified in the assessment of body image: (1) a perceptual component of body size and shape and (2) an emotional or attitudinal component as an index of body satisfaction (Skrzypek et al., 2001; Slade, 1988).

It has become increasingly important to examine this issue during adolescence as numerous studies have demonstrated a clear trend of increased childhood and adolescent obesity (Chinn & Rona, 2001; Ogden et al., 2002; Strauss et al., 2001; Thompson et al., 2002; Tremblay et al., 2002), as well as a relationship between adolescence and eating disorders (Hsu, 1990; Lucas, Beard, O'Fallon, & Kurland, 1991). A study investigating the changes, between 1981 and 1996, in the body mass index (BMI) of Canadian children and adolescents (7 to 13 years of age) reported a 22% and 14% increase in the number of overweight boys and girls, respectively (Tremblay et al., 2002). With respect to body perception, some reports have indicated that obese individuals show no difference in body perception when compared to controls (Gardner et al., 1987; Gardner et al., 1989b; Probst et al., 1995a); in contrast, other studies have reported that obese individuals overestimate the size of their body (Gardner et al., 1989a; Gardner et al., 1988a; Rhodes & O'Neil, 1997). These conflicting results are likely due to methodological variations. Nevertheless, these changes in the size and shape of child and adolescent bodies stress the importance
of examining how such physical transformations interact with the image of the body in the adolescent’s mind.

Clinically, perception of one’s own body may be of particular importance in anorexia and bulimia nervosa, two eating disorders that often begin during adolescence (Hsu, 1990). Perhaps not surprisingly, a larger perceived-size and smaller ideal body-size may predict higher eating-disorder scores in adolescence (Gardner et al., 2000). Thus, a fundamental understanding of adolescent body-perception may offer insight into the development of anorexia and bulimia nervosa.

Over the past four decades, numerous techniques have been used to assess body image in adolescents and adults. These techniques may be divided into three major categories: (1) tools that do not utilise any visual presentation of a body image such as questionnaires, the image-marking technique, and visual size-estimation technique (Askevold, 1975; Maloney et al., 1988; Mendelson et al., 2001; Reitman et al., 1964; Slade et al., 1973); (2) tools that utilise a mock silhouette or body image to represent the subject such as the Figure Rating Scale and Collins pictorial figures (Collins, 1991; Stunkard et al., 1983); and (3) tools that utilise distortion of real body-images such as distorting mirrors, video-based distortions, and computer-morphing software (Allebeck et al., 1976; Benson et al., 1999; Probst et al., 1992; Traub et al., 1964). Computer-based morphing tools are the latest addition; these techniques simulate life-like changes in body shape and size (Benson et al., 1999; Gardner et al., 2004; Gruber et al., 1999; Harari et al., 2001; Sands et al., 2004; Shibata, 2002; Smeets, 1999; Stewart et al., 2001). Even the most recent software tools, however, may not be ideal for the study of adolescent body-perception. To date, some tools use reference data from adult bodies (Benson et al., 1999); thus, the defined variation in adult body-shape would fail to account for the degree
of variations in adolescent bodies due to growth and sexual maturation. Another potential limitation of these various computer- graphic techniques involves the morphing of individual body- parts independently of each other with subsequent smoothing of adjacent areas. This type of morphing fails to take into account the natural covariation of individual body- parts such as a correlated hip and thigh enlargement.

In order to address some of these methodological issues, we wished to use a modelling approach for body- shape morphing that was data- driven and not constrained by a priori information. Principal components analysis (PCA) of a large number of landmarks from a set of training images was thus selected to model body size and shape variations among healthy adolescents. Principal components analysis permits the integration of data regarding all body parts simultaneously into a single model with multiple image views. This characterization of variation across all body parts provides the opportunity to morph body images in a naturalistic global manner.

Here, we describe the development of a computer- morphing tool specifically designed for the testing of adolescent body- perception. In order to define natural variations in body shape in an adolescent population, a novel Adolescent Body- Shape Database (AdoBSD) was created consisting of front and side images of adolescent bodies; age, sex, height, and weight data for each individual were also included. Principal components analysis of manually- placed landmarks on these images was used to identify group- wise covariations between body parts across the two image views. The established principal components model was subsequently used to create a novel Adolescent Body- Morphing Tool (AdoBMT). This tool was used to distort real images quantitatively according to natural covariations in adolescent body shape as defined by the individual principal components (PCs). This step produced morphed but realistic body- images of
varying size that may be used in future tasks testing adolescent body-perception and satisfaction.

In addition, we developed a two dimensional (2D) anthropometric system to characterize the body dimensions of both real images (i.e., source population) and morphed images. This allowed us to characterize the induced variations in body shape using parameters similar to 3D anthropometrics such as circumferences and BMI values. We then completed a behavioural study examining the perceptual realism of the morphed body-images. In an effort to identify appropriate morphing parameters for future experiments, we report distinct distortion effects as well as response profiles for specific PCs. The current paper is organized into three sections detailing: (1) the Adolescent Body-Shape Database (AdoBSD), (2) the Adolescent Body-Morphing Tool (AdoBMT), and (3) a behavioural validation experiment for the AdoBSD and AdoBMT.

2.4 Adolescent Body-Shape Database (AdoBSD)

2.4.1 Subjects

Male and female subjects ranging in age from 9 to 17 years were recruited from the Montreal community through local advertising (see Results for a description of the sample). The Research Ethics Board of the Montreal Neurological Institute and Hospital approved all experimental protocols. Informed parental/guardian consent and subject assent were obtained for all participants.
2.4.2 Methods

Subject Preparation

All subjects were asked to change into a white cotton undershirt, red Lycra bodysuit, and red fleece ski mask; various sizes of the Lycra bodysuit were available. The undershirt was worn underneath the bodysuit while the ski mask was utilised to protect the subject’s identity. The Lycra bodysuits were purchased from a local dance-equipment supplier while the cotton undershirts and ski masks were purchased from a local general merchandise store.

The date of birth and sex were recorded, and height and weight measurements obtained at the beginning of the session. The child was positioned within the standard background and two digital images were acquired. Movie certificates were given to all subjects as compensation for their time and inconvenience.

Image Acquisition

To minimize positional variations in image acquisition, a standard layout was used for all subjects. A single navy-blue piece of fleece material (203 x 287 cm) was used as a background. The material was pulled taut within a rigid wooden frame with a portion of the material arranged on the floor. To indicate a consistent standing position for each subject, pieces of grey tape were placed on the wall and floor to delineate arm and foot positions, respectively (Figure 2.1). Images were acquired in a room (7.5 m x 3.9 m) that had unimpeded fluorescent lighting and afforded the participant privacy.

Images were acquired from both front and side views. These views were selected as the most familiar to potential subjects as they reflect common mirror perspectives. For that reason, other views such as a back silhouette image were not included. For the front
view, subjects were instructed to stand facing the camera with their feet parallel to each other, 38 cm apart, within the tape borders placed on the floor. The experimenter positioned the arms of each subject between the tape borders on the wall. The distance between the hands along the horizontal plane was 91 cm. Subjects were asked to look directly into the camera lens (through the ski mask) and to maintain a proper posture with rigid arms and legs (Figure 2.1a).

For images in the side view, subjects were instructed to rotate 90° to the left such that their right side was facing the camera. Each subject placed his/her right foot into the (right) foot border. Subjects positioned both feet tightly together and raised their right arm at a 90° angle to their torso (Figure 2.1b).

Figure 2.1: Subject image position and image linear registration. Subjects dressed in a red bodysuit were positioned in standard poses in front (a) and side (b) views. Manual tape borders were placed on the blue photography background as indicated by the
measurements in order to standardize subject position. Manual reference tag-points (i.e.,
black circles) were positioned at the corners of the tape borders for subsequent
translation, rotation, and scaling of the image.

Images were acquired using a Canon PowerShot G2 digital camera (Canon Inc.,
Tokyo, Japan). Image resolution was 2272 x 1704 pixels with automatic white-balance.
Natural lighting (i.e., no flash) was used to limit glare. The camera was mounted on a
Velbon video tripod (Velbon SX-621, Tokyo, Japan) with the distance between the
camera lens midpoint and the ground equal to 109 cm. A constant distance of 194 cm was
maintained between the subject and the camera. Minimum camera zoom was utilised for
all images.

2.4.3 Results

A total of 160 adolescents (73 males, 87 females) were recruited for the AdoBSD.
Frequency distributions for subject age and BMI are detailed in Figures 2.2a and 2.2b,
respectively. The mean ages for male and female subjects were 12.78 years [standard
error of the mean (S.E.M) = 0.25] and 12.95 years (S.E.M. = 0.25), respectively. The
mean BMI values for male and female subjects were 19.91 kg/m² (S.E.M. = 0.40) and
19.64 kg/m² (S.E.M. = 0.35), respectively. Independent samples t-tests revealed no
significant differences between males and females for age or BMI (p > 0.05).
Figure 2.2: Adolescent Body-Shape Database. Age (a) and body mass index (b) frequency distributions for males and females are presented.
2.5 Adolescent Body-Morphing Tool (AdoBMT)

2.5.1 Methods

Linear registration

In order to perform a comparative analysis of body shapes, images from the AdoBSD had to be first positioned into a single spatial frame of reference. Reference tags were manually positioned on both front and side images using the interactive volume display and point-tagging program, Register (David MacDonald: www.bic.mni.mcgill.ca/software/register/register.html). Six tags in the front view and four tags in the side view were placed at predetermined corners of the tape borders (Figure 2.1). A linear registration procedure was completed using Matlab 7.1 (The Mathworks, Natick, Massachusetts). Registration was used to match each image tag-point on the background tape markers with those from a selected reference using a transformation with 7 degrees of freedom (i.e., 3 rotations, 3 translations, 1 scale). The objective of this linear registration was to remove the global effects of pose, perspective, and variation in the subjects' position relative to the background.

Body-tagging & Interrater Reliability

Following linear registration, two raters manually positioned 36 (front view) and 18 (side view) body tag-points at defined body landmarks (Figure 2.3). These body tag-points were identified according to adapted anthropometric definitions (Lohman, Roche, & Martorell, 1991). The origin of our coordinate system was located at the bottom left corner of the images. After tagging, the background of each image was set to black in order to remove all visual cues in the morphed images. Two raters completed the body-
tagging process twice on the same 20 subjects in order to assess interrater reliability.

Figure 2.3: Standardized body tag-points. Manual body tag-points (i.e., black circles) were placed on each subject body, in accordance with adapted anthropometric definitions.

**Point Distribution Model**

All modelling and image morphing was completed with Matlab 7.1. In order to capture shape variations across individuals, a point distribution model (PDM) was used (Cootes, Taylor, Cooper, & Graham, 1995). Point distribution models have been used extensively in the medical imaging literature; they rely on the assumption that global object-change variations can be reliably estimated by modelling the spatial distribution of series of appropriately placed and corresponding landmarks positioned on object representations.

Our model was built using data from both male and female subjects across all ages. Proper sampling of the object boundary is an important element of the model and thus, we
identified 36 tag-points in the front view and 18 tag-points in the side view, corresponding to the edges of body areas of morphological interest. The PDM was created by completing PCA of the entire dataset of body tag-points (i.e., 160 subjects x [36 front and 18 side tag-points]) as represented by continuous vectors \( v \) of \((x,y)\) coordinates (Cootes et al., 1995), concatenating front and side views together. With PCA, one can express each instance of \( v \) as:

\[
v = \bar{v} + P_v B_v
\]

where \( \bar{v} \) is the mean normalized shape vector, \( P_v \) is a set of orthogonal modes of variation, and \( B_v \) is a set of coordinate parameters. This representation spans a multidimensional ellipsoid including all shape instances from the dataset, as well as other possible shape instances that may not be present in the database.

In order to identify the contribution of each principal direction in the description of the total variance of the system, the ratio of relative importance of the eigenvalue \( \lambda_k \) associated with the eigenvector or principal component \( k \) is used

\[
r_k = \frac{\lambda_k}{\sum_{j=1}^{p} \lambda_j}
\]

where the fraction \( r_k \) is the relative importance for eigenvalue \( \lambda_k \), over the sum of all \( \lambda \), since \( p \) is the total number of eigenvectors.

*Image morphing*

Morphed body-images were created by adding multiples (up to \( \pm 0.8 \) S.D. in 0.1 S.D. steps) of the standard deviation (S.D.) of the mean of each PC to the \((x,y)\)
coordinates of the body tag-points of the original body-images. These transformed points were then used as anchors to derive a smooth 2D thin-plate spline transformation (Bookstein, 1989), thereby morphing the original images to produce a body of greater or smaller size. The thin-plate spline is the 2D analog of the cubic spline in one dimension. We used it here to derive the transformation field interpolating between pre- and postwarped points.

The morphed images were then linearly transformed again (i.e., translation and rotation but no scaling) to the average shape $\overline{V}$, ensuring that all images were properly centred when presented on the computer screen.

Principal components analysis characterizes covariations between body tag-points; therefore, the morphing process resulted in a dynamic procedure, whereby body parts that were found to covary among database subjects were also morphed simultaneously as dictated by the PCs. Moreover, PCA calculated covariations between tag-points in both front and side body-images, thereby delineating the concurrent changes in body shape and size across the two perspectives in a global manner.

2D Anthropometric Measurements

Other body-morphing techniques often quantify the degree of body distortion using a global percentage-change value without any direct link to physiological body measurements (Harari et al., 2001; Sands et al., 2004). In order to quantify (1) the real body dimensions of the 160 AdoBSD subjects and (2) the anthropometric-like changes induced by application of each PC to the body images, we first defined a series of 2D anthropometric measures within our images that best mimic 3D anthropometric measures.
The use of a 2D anthropometric system allows for the qualitative and quantitative assessment of output stimuli as well as a biological characterization of morphing, thereby giving researchers the capacity to select morphing parameters based on body morphology.

These 2D measures were calculated as caliper distances between certain body tag-points as graphically represented in Figure 2.4. Anthropometric distances were calculated as the difference between the respective $x$ and $y$ coordinates for each body-tag point involved, converted into metric units using a pixel/centimetre (cm) constant. Distances were calculated for both real and morphed body-images.

![Figure 2.4: Two-dimensional anthropometric measures. Dark black lines indicate the](image)

Figure 2.4: Two-dimensional anthropometric measures. Dark black lines indicate the
Characterization of Body Morphing using Body Mass Index (BMI)

Although the 2D anthropometric system allows for the characterization of quantitative changes in body parts with changing levels of imposed distortion, the system fails to provide global information about potential changes in BMI. The use of BMI in characterizing changes imposed by the AdoBMT would permit the use of biologically relevant terminology and facilitate comparison of the morphed body-images to real-life measurements of potential volunteers.

Not knowing the weight of the distorted bodies represents an obvious difficulty for calculating the BMI of morphed images. We estimated virtual BMI values from an estimate of body-volume and predicted the virtual BMI values using the observed linear relationship between the total body-volume and BMI of the real 160 subjects (see below). The body-volume of an individual was estimated by segmenting the body into three cylindrical components: (1) torso, (2) right leg, and (3) left leg. The radius and height of each of the three body cylinders were calculated using the distances between established body tag-points. Individual volumes were determined for each of the cylinders and then summed for a grand volume total.

2.5.2 Results

Body-tagging & Interrater Reliability

Two raters (R.A. and S.D.) tagged a total of 40 images including the front and side views of 20 subjects. In the front view, some tag-points were subject to wide positional
variation across participants. For this reason, four tag-points were removed from the PCA model (i.e., left/right knee and left/right hand). The knee tag-points were excluded as the raters could not consistently identify the middle of the kneecap in each image. The hand tag-points were removed due to the variable nature of the arm position for individual subjects. In the side view, a total of three body tag-points were removed from the analysis including the finger and two distal-thigh points. The finger point was excluded due to the great variability in arm position across subjects. The distal-thigh points were removed due to the inability of the raters to identify consistently those points in the images across subjects. Thus, a total of 47 tag-points were included in the final PC analysis.

In order to measure interrater reliability of the positioning of all 54 body tag-points, two dependent variables were assessed separately: (1) mean distance between the raters’ points as an indicator of tagging error and (2) correlation between anthropometric measures derived from each rater’s tag-points. In the first method, the mean Euclidean distance between the points of two raters was calculated for each body tag-point. In order to identify body tag-points where the tagging error was significantly different from the minimum error of zero, multisample 95% confidence intervals were used with the minimum tagging-error value arbitrarily set as a population mean of zero. Our analysis revealed that no body tag-point fulfilled the statistical criteria for a mean error distance of zero (p > 0.05, Tables 2.1.1 & 2.1.2).
Table 2.1.1: Interrater reliability: Confidence intervals for the mean error distance, front view (cm)

<table>
<thead>
<tr>
<th>Tag Point</th>
<th>Picture Side</th>
<th>Body Part</th>
<th>Mean (cm)</th>
<th>Confidence Interval (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Left</td>
<td>Small toe</td>
<td>0.32</td>
<td>0.19-0.45</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Big toe</td>
<td>0.29</td>
<td>0.23-0.35</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Medial ankle</td>
<td>0.45</td>
<td>0.26-0.64</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Medial calf</td>
<td>1.00</td>
<td>0.65-1.34</td>
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<tr>
<td>5</td>
<td></td>
<td>Knee</td>
<td>1.01</td>
<td>0.72-1.29</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>Medial proximal thigh</td>
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<td>0.43-1.00</td>
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<td>Right</td>
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<td></td>
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<td>Picture Side</td>
<td>Body Part</td>
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<td>Confidence Interval (cm)</td>
</tr>
<tr>
<td>-----------</td>
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<td>-------------------------</td>
<td>-----------</td>
<td>--------------------------</td>
</tr>
<tr>
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<td>Hip upper quarter</td>
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<tr>
<td>22</td>
<td></td>
<td>Breast</td>
<td>1.89</td>
<td>1.48-2.31</td>
</tr>
<tr>
<td>23</td>
<td></td>
<td>Collarbone</td>
<td>0.88</td>
<td>0.64-1.13</td>
</tr>
<tr>
<td>24</td>
<td></td>
<td>Shoulder</td>
<td>1.51</td>
<td>1.04-1.99</td>
</tr>
<tr>
<td>25</td>
<td>Left</td>
<td>Shoulder</td>
<td>1.62</td>
<td>1.15-2.09</td>
</tr>
<tr>
<td>26</td>
<td></td>
<td>Collarbone</td>
<td>1.25</td>
<td>0.94-1.56</td>
</tr>
<tr>
<td>27</td>
<td></td>
<td>Breast</td>
<td>2.38</td>
<td>1.84-2.92</td>
</tr>
<tr>
<td>28</td>
<td></td>
<td>Waist</td>
<td>0.97</td>
<td>0.64-1.31</td>
</tr>
<tr>
<td>29</td>
<td></td>
<td>Lateral proximal thigh</td>
<td>0.70</td>
<td>0.44-0.96</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td>Hip midpoint</td>
<td>0.97</td>
<td>0.58-1.36</td>
</tr>
<tr>
<td>31</td>
<td></td>
<td>Hip upper quarter</td>
<td>0.87</td>
<td>0.43-1.31</td>
</tr>
<tr>
<td>32</td>
<td></td>
<td>Hip lower quarter</td>
<td>0.83</td>
<td>0.62-1.04</td>
</tr>
<tr>
<td>33</td>
<td></td>
<td>Finger</td>
<td>0.22</td>
<td>0.15-0.29</td>
</tr>
<tr>
<td>34</td>
<td></td>
<td>Lateral distal thigh</td>
<td>0.91</td>
<td>0.68-1.13</td>
</tr>
<tr>
<td>35</td>
<td></td>
<td>Lateral calf</td>
<td>1.39</td>
<td>1.01-1.77</td>
</tr>
<tr>
<td>36</td>
<td></td>
<td>Lateral ankle</td>
<td>0.42</td>
<td>0.34-0.51</td>
</tr>
</tbody>
</table>
Table 2.1.2: Interrater reliability: Confidence intervals for the mean error distance, side view (cm)

<table>
<thead>
<tr>
<th>Tag Point</th>
<th>Body Part</th>
<th>Mean (cm)</th>
<th>Confidence Interval (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Upper back</td>
<td>1.94</td>
<td>0.91-2.96</td>
</tr>
<tr>
<td>2</td>
<td>Lower back</td>
<td>1.05</td>
<td>0.79-1.31</td>
</tr>
<tr>
<td>3</td>
<td>Posterior hip</td>
<td>0.54</td>
<td>0.31-0.76</td>
</tr>
<tr>
<td>4</td>
<td>Posterior proximal thigh</td>
<td>1.47</td>
<td>1.13-1.80</td>
</tr>
<tr>
<td>5</td>
<td>Posterior distal thigh</td>
<td>1.56</td>
<td>0.93-2.19</td>
</tr>
<tr>
<td>6</td>
<td>Posterior midthigh</td>
<td>1.54</td>
<td>1.13-1.94</td>
</tr>
<tr>
<td>7</td>
<td>Posterior calf</td>
<td>1.00</td>
<td>0.65-1.34</td>
</tr>
<tr>
<td>8</td>
<td>Heel</td>
<td>0.55</td>
<td>0.42-0.68</td>
</tr>
<tr>
<td>9</td>
<td>Right foot small toe</td>
<td>0.21</td>
<td>0.16-0.25</td>
</tr>
<tr>
<td>10</td>
<td>Right foot big toe</td>
<td>0.26</td>
<td>0.21-0.30</td>
</tr>
<tr>
<td>11</td>
<td>Anterior distal thigh</td>
<td>1.47</td>
<td>0.78-2.16</td>
</tr>
<tr>
<td>12</td>
<td>Anterior proximal thigh</td>
<td>1.39</td>
<td>1.05-1.73</td>
</tr>
<tr>
<td>13</td>
<td>Anterior midthigh</td>
<td>1.19</td>
<td>0.79-1.60</td>
</tr>
<tr>
<td>14</td>
<td>Anterior hip</td>
<td>1.30</td>
<td>0.88-1.73</td>
</tr>
<tr>
<td>15</td>
<td>Anterior belly</td>
<td>0.76</td>
<td>0.41-1.12</td>
</tr>
<tr>
<td>16</td>
<td>Right breast</td>
<td>1.08</td>
<td>0.74-1.41</td>
</tr>
<tr>
<td>17</td>
<td>Finger</td>
<td>0.41</td>
<td>0.26-0.56</td>
</tr>
<tr>
<td>18</td>
<td>Head</td>
<td>0.62</td>
<td>0.46-0.79</td>
</tr>
</tbody>
</table>
In practical terms, however, the confidence intervals for only 7 out of 54 body tag-points showed a maximum interval value greater than 20 pixels. These seven body tag-points include the knee, breast, and shoulder in the front view and the upper back and distal thigh in the side view. This measurement of error should be considered relative to the surface area of the computer screen. Given that all body images, whether they are real or morphed, will be presented on a computer screen, it is appropriate to assess interrater reliability differences in the context in which the images will be used. On a standard laptop screen with 1024 x 768 pixels, an interrater reliability difference of 20 pixels represents approximately 2% of the screen. From a visual-perception perspective, we contend that such a small difference is inconsequential.

A total of 14 anthropometric measures were calculated for both raters for the same subset of 20 subjects. Individual Pearson’s correlations were conducted for each anthropometric measure and the results indicate that there were exceptionally strong positive correlations \((r \geq 0.90, \ p < 0.05)\) between the two raters’ anthropometric measures, with the exception of the biacromial breadth measurement \((r = 0.492, \ p < 0.05)\) (Table 2.2).
### Table 2.2: Interrater reliability - Anthropometric measures

<table>
<thead>
<tr>
<th>Anthropometric Measure</th>
<th>Pearson’s correlation (r)</th>
<th>p - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virtual height</td>
<td>0.997</td>
<td>0.00</td>
</tr>
<tr>
<td>Sitting height</td>
<td>0.985</td>
<td>0.00</td>
</tr>
<tr>
<td>Leg length</td>
<td>0.989</td>
<td>0.00</td>
</tr>
<tr>
<td>Shoulder width/ Biacromial breadth</td>
<td>0.492</td>
<td>0.03</td>
</tr>
<tr>
<td>Hip width A/Bicristal breadth</td>
<td>0.988</td>
<td>0.00</td>
</tr>
<tr>
<td>Hip width B/Bicristal breadth</td>
<td>0.981</td>
<td>0.00</td>
</tr>
<tr>
<td>Left calf width</td>
<td>0.967</td>
<td>0.00</td>
</tr>
<tr>
<td>Right calf width</td>
<td>0.966</td>
<td>0.00</td>
</tr>
<tr>
<td>Left thigh width</td>
<td>0.902</td>
<td>0.00</td>
</tr>
<tr>
<td>Right thigh width</td>
<td>0.973</td>
<td>0.00</td>
</tr>
<tr>
<td>Waist</td>
<td>0.995</td>
<td>0.00</td>
</tr>
<tr>
<td>Hip</td>
<td>0.982</td>
<td>0.00</td>
</tr>
<tr>
<td>Belly</td>
<td>0.991</td>
<td>0.00</td>
</tr>
<tr>
<td>Side thigh</td>
<td>0.978</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Point Distribution Model and PCA Results

The mean location in $(x,y)$ coordinates for each body tag-point was calculated so as to provide a visual representation of the average body for both males and females in the front and side images. The final PCA characterized the covariation between body tag-points with the first 8 eigenvectors accounting for 96.3% of the distribution variation (Table 2.3). Individual PCs can be depicted graphically as successive standard deviation increments are added to the mean body-shape (Figure 2.5).

Table 2.3: Principal components analysis

<table>
<thead>
<tr>
<th>Principal Component (PC)</th>
<th>Cumulative Weight (%)</th>
<th>Individual Weight (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>82.9</td>
<td>82.9</td>
</tr>
<tr>
<td>2</td>
<td>88.9</td>
<td>6.0</td>
</tr>
<tr>
<td>3</td>
<td>91.4</td>
<td>2.5</td>
</tr>
<tr>
<td>4</td>
<td>93.3</td>
<td>1.9</td>
</tr>
<tr>
<td>5</td>
<td>94.4</td>
<td>1.2</td>
</tr>
<tr>
<td>6</td>
<td>95.3</td>
<td>0.87</td>
</tr>
<tr>
<td>7</td>
<td>95.8</td>
<td>0.53</td>
</tr>
<tr>
<td>8</td>
<td>96.3</td>
<td>0.37</td>
</tr>
</tbody>
</table>
Figure 2.5: Principal component analysis-based body morphing. On the left, line drawings indicate changes in body size and shape with sequential addition of distortion to the \((x,y)\) coordinates of the mean location of the body tag-points. On the right, a female subject is morphed using PC4 in the front and side perspectives. Images represent (from left to right) -0.4, -0.2, +0.2, and +0.4 S.D. from the mean of each respective PC.

All eight PCs were applied to male and female bodies. As PCA determines the covariance between body tag-points, distortion using the PCs displayed covariance in body-part distortion. As the morphing was done using front and side views concurrently, physical changes that may not have been identified in the front perspective, such as buttock size, were clearly changed in the side perspective. This confirmed the importance of a PC analysis in which covariation of body parts in both front and side images was determined.
We measured the real 2D anthropometric measures of the AdoBSD subjects (n=160). A multivariate analysis with subject age and BMI as covariates revealed a significant effect of subject gender \[F(13, 144) = 11.133, p < 0.001\] on a number of measures including virtual (i.e., image-derived) height, shoulder width, leg length, waist, belly, and thigh width (Figure 2.6).
Figure 2.6: Real 2D anthropometric measurements of the Adolescent Body-Shape Database. A multivariate analysis revealed a significant effect of subject gender on 2D anthropometric measurements. Significant differences between males and females were reported for the following anthropometric measures: virtual height, leg length, shoulder width, thigh width, waist width, and belly width ($p < 0.05$).

2D Anthropometric Measurements, Morphed Images

The 2D anthropometric measures were also used to quantify physical changes induced in the body images by the AdoBMT. Change was described as the percent change relative to real (i.e., nonmorphed) measures calculated for the 160 adolescents in the AdoBSD. These changes are calculated as slopes in order to identify the rate of change as a function of the amount of distortion introduced, the latter defined by the
standard deviation of the mean of each PC. Slopes were calculated for each PC for all 14 anthropometric measures. These results are summarized in Table 2.4.

Table 2.4: Body-morphing software – Body-shape changes.

<table>
<thead>
<tr>
<th>ID</th>
<th>Body Part</th>
<th>Relative % Change/Standard Deviation of the Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>PC1</td>
</tr>
<tr>
<td>1</td>
<td>Virtual height</td>
<td>92.91</td>
</tr>
<tr>
<td>2</td>
<td>Sitting height</td>
<td>78.45</td>
</tr>
<tr>
<td>3</td>
<td>Leg length</td>
<td>107.42</td>
</tr>
<tr>
<td>4</td>
<td>Shoulder width</td>
<td>99.04</td>
</tr>
<tr>
<td>5</td>
<td>Hip A</td>
<td>91.40</td>
</tr>
<tr>
<td>6</td>
<td>Hip B</td>
<td>74.68</td>
</tr>
<tr>
<td>7</td>
<td>Left calf</td>
<td>90.50</td>
</tr>
<tr>
<td>8</td>
<td>Right calf</td>
<td>98.08</td>
</tr>
<tr>
<td>9</td>
<td>Left thigh</td>
<td>73.87</td>
</tr>
<tr>
<td>10</td>
<td>Right thigh</td>
<td>75.43</td>
</tr>
<tr>
<td>11</td>
<td>Waist</td>
<td>66.30</td>
</tr>
<tr>
<td>12</td>
<td>Hip</td>
<td>91.86</td>
</tr>
<tr>
<td>13</td>
<td>Belly</td>
<td>42.85</td>
</tr>
<tr>
<td>14</td>
<td>Side thigh</td>
<td>91.11</td>
</tr>
</tbody>
</table>

Note: The rate of change in each anthropometric measure is expressed as a slope (i.e., relative percent change/standard deviation of the mean of each PC).
BMI Characterization of Body-Image Morphing

Although the slopes described above provide detailed numerical values identifying whether certain body parts grow larger or smaller with changing distortion levels, they do not provide a global outlook of change as defined by BMI. A significant positive correlation was found between the real BMI values of the 160 AdoBSD subjects and calculated total body-volume \([r = 0.585, p < 0.001; F(1,158) = 82.16, p < 0.001, \text{Figure 2.7}]\). Based upon this linear relationship, the changes in BMI induced by the AdoBMT were calculated from the virtual body-volume, and the ranges of these virtual BMI induced by each PC are graphically presented in Figure 2.8. All PCs showed a significant cubic relationship between virtual BMI and the degree of distortion \((p < 0.001)\).

Figure 2.7: Linear regression of Adolescent Body-Shape Database body mass index and total body-volume. A significant linear relationship between BMI and total cylindrical body-volume \([F(1,158) = 82.16, p < 0.001]\) was established. Linear regression analysis
determined a function \[\text{BMI} = 12.379 + 101.699 \times \text{total cylindrical body-volume} \] to estimate the BMI of a given body.

Figure 2.8: Estimated mean body mass index of morphed body-images. Significant cubic
relationships were established between estimated BMI and level of distortion for PC1 (a) and PCs 2-8 (b), \( p < 0.05 \).

2.6 Behavioural Validation of the AdoBMT

2.6.1 Subjects

All experimental protocols were granted ethics approval under the provisions of the Research Ethics Board of the Montreal Neurological Institute and Hospital. Healthy adult volunteers (18 to 46 years) were recruited from the Montreal community through local advertisements. Informed consent was obtained for all participants. All subjects included in the study reported no history of or current serious medical condition.

A total of 72 subjects (38 females) were recruited for the study. Two female subjects were excluded following testing as they reported suffering from a prior psychiatric illness. One female was excluded as she halted testing due to physical illness. A final total of 69 healthy subjects were included in the analysis (35 females, 34 males). The mean age and BMI were: females: 22.71 years (S.E.M. = 1.0), 22.63 kg/m\(^2\) (S.E.M. = 0.58); males: 23.74 years (S.E.M. = 1.0), 23.88 kg/m\(^2\) (S.E.M. = 0.58). Independent samples t-tests revealed no significant effect of gender for subject age and BMI (\( p > 0.05 \)).

2.6.2 Methods

Height and weight measurements were recorded for all subjects. Testing was completed during two 40-minute sessions with an approximate 4-hour break between the sessions. The entire experiment was implemented using Presentation software (Version
Subjects were presented with real and morphed body-images from the AdoBSD (see below) and asked to rate each body image on an integer scale as to whether they agreed or disagreed with a statement declaring the body to be odd. The term “odd” was not defined further in order to prevent biasing subjects to particular body parts or shapes. The scale ranged from (-3) to (+3) where (-3) indicated that they disagreed with the statement (i.e., the body was not odd) and (+3) that they agreed with the statement (i.e., the body was odd).

The AdoBSD was divided into eight stimuli categories as defined by gender, the median age of the AdoBSD (i.e., 13 years), and the median BMI of each gender-age category. A different randomly-selected combination of eight AdoBSD children (i.e., one from each category) was chosen for each subject in order to ensure maximum sampling of the AdoBSD. For each AdoBSD child, real images in front and side views were used. Front and side body-images were also morphed with PC2, PC4, and PC5 and with ± 0.1, ± 0.3, and ± 0.5 levels of distortion with the estimated BMI of the morphed bodies ranging from 16.5-24.1 kg/m². PC1 was not selected as it morphs significantly the height of the body, a factor of no experimental interest to the authors. PC3 was also not used as we discovered that warping in the knee region did not provide realistic body-images. Thus, the remaining three PCs (PC2, PC4, PC5) that accounted for the most model variation were selected. Although it would have been ideal to include also PCs 6-8, the duration of such an experiment was deemed excessive and taxing for the subjects, potentially jeopardizing the quality of the acquired data. Consequently, subjects were presented with a total of 304 different body-images (288 morphed images [8 AdoBSD...
children x 2 views x 3 PCs x 6 distortion levels] plus 16 real images [8 AdoBSD children
x 2 views]) with each image repeated six times.

All images were randomly presented for 1000 ms followed by a 250 ms
interstimulus interval. The “oddness” scale was then presented on the screen for a
maximum of 2000 ms during which subjects were requested to make their response. An
intertrial interval of 250 ms was used.

2.6.3 Results

For the real images, a repeated measures analysis of variance (ANOVA) was
conducted with one between-subjects variable (subject gender) and four within-subjects
variables; the latter included image gender, image view (front versus side), age of the
image (high [≥13 yr] versus low [<13 yr]), and BMI of the image (high versus low). A
significant three-way interaction between image view, image BMI, and subject gender
was found [F(1,67) = 5.307, p < 0.05; Figure 2.9a]. Subsequent simple main effects
analysis and pairwise comparisons with Bonferroni correction revealed that female
subjects rated low-BMI images as significantly less odd than high-BMI images (p <
0.05); note that this finding was observed even though our healthy adult volunteers were
being shown the real images of adolescent bodies.

For the morphed images, a repeated measures ANOVA was completed with subject
gender as a between-subjects variable and five within-subjects variables; the latter
included image gender, image view (front versus side), type of distortion (PC2, PC4,
PC5), direction of distortion (large versus small morph-size), and amount of distortion (±
0.1, ± 0.3, ± 0.5 S.D. of the mean of the PC). Analysis of variance revealed a significant
five-way interaction between all of the within-subjects variables \(F(4,268) = 5.661, p < 0.001\). This complex interaction, however, would likely fail to provide any substantial insight into the data. Consequently, we examined the significant three-way interaction between our three variables of interest (i.e., amount of distortion, type of distortion, image view) \(F(4,268) = 11.660, p < 0.001\; \text{Figure 2.9b}\). Simple main effects analysis and pairwise comparisons with Bonferroni correction revealed a significant effect of image view, with the front view showing significantly higher mean scores (i.e., higher "oddness") than the side view for all conditions \((p < 0.05)\). In addition, an effect of principal component was revealed, whereby PC2 morphing was found to result in significantly lower (i.e., less odd) mean scores than PC4 or PC5 across all conditions \((p < 0.05)\). Finally, a significant distortion effect was found only for PC4 and PC5, and not PC2, with higher mean scores associated with greater introduced distortion \((p < 0.05)\).

In order to determine the relative degree of "oddness" associated with morphed body-images, 95% confidence intervals of the mean scale scores for the real front and side photographs were used as statistical baseline values. Mean scale scores for 0.3 and 0.5 S.D. of distortion for PCs 4 and 5 were found to be greater than the maximum interval level.
Figure 2.9: A significant three-way interaction between subject gender, image perspective, and image body mass index on mean scale scores was detected (a). Female subjects rated low-BMI body images as significantly less odd than high-BMI images (p <
0.05). A three-way interaction between image view, type of distortion, and amount of distortion was found to be significant (b). Front images were found to be more odd than side images (p < 0.05). PC2-morphed images were found to be less odd than PC4 or PC5 images (p < 0.05). A significant distortion effect was also noted, with greater distortion associated with a higher mean score (i.e., more odd) (p < 0.05).

2.7 Discussion and Conclusions

We have described a novel age-specific body-morphing tool that transforms 2D (front and side view) images of adolescent bodies according to the natural covariations across individual body-parts. Principal components analysis of landmarks positioned on the 320 images constituting our database revealed eight primary principal components that characterized 96.3% of the covariation between body tag-points across male and female subjects. This analysis also revealed covariation between tag-points within and between front and side views. These PCs, when applied to real body-images using our image-morphing software, resulted in the standardized distortion of various body dimensions including the body's height, and the size of the shoulders, waist, hip, thighs, belly, and calves. These changes in body shape and size were generated such that specific body-parts were morphed simultaneously as dictated by the variation present in the subject population of our database. We then characterized the resulting image distortion using both a 2D anthropometric system and an estimation of BMI from a calculation of total body-volume.

The use of a point distribution model based upon PCA of the covariance of the tag-point coordinates was successful in that it effectively simulated global changes in
adolescent morphology. The PCA results clearly showed that body-part changes rarely occurred in isolation. When morphing body images, covariances must be incorporated if realism is to be maintained and if reliable assessment of perceptual changes is to be achieved.

The AdoBMT was characterized using two quantitative methods including a 2D (i.e., image-derived) anthropometric system and an estimated BMI. Analysis of the real BMI for all 160 AdoBSD subjects revealed a significant linear relationship between the real BMI and body-volume estimated from the 2D images. This linear relationship allowed us to estimate BMI for all morphed body-images. The results clearly indicated that changes in body shape induced by the AdoBMT translated into tangible changes in BMI. The range of BMI change induced by each PC was proportionate to the amount of variation accounted for in the point distribution model by each PC. Standardized morphing changes were also found to result in a significant cubic relationship with changes in estimated BMI. In spite of linear changes induced in the anthropometric measures used to calculate total body-volume, cubic changes in estimated BMI would be produced by virtue of the volume calculation. Although the precision of the BMI estimation may be broad in nature, the results clearly demonstrate that body size and shape changes induced by the AdoBMT may be characterized quantitatively using a biologically-relevant descriptor.

The unique nature of our PCA-based analyses provides us with various types of morphed images. For example, PC1 induces a gross distortion of body shape, driven primarily by the subject’s height, whereas the other PCs offer an opportunity for a subtler distortion with emphasis on particular body regions (i.e., lower body) while always respecting the natural variations between body parts. In addition, the degree of distortion
may be manipulated by varying the standard deviation of the mean of the PC used in the distortion. The amount of distortion introduced is entirely arbitrary; for practical reasons, we selected a standard-deviation range of -0.8 to +0.8. With this range of distortion across all eight PCs, the maximum BMI range of the morphed images was 12.52-51.79 kg/m$^2$. Thus, with a database of 160 adolescent images and the flexibility in our distortion technique, we generated a library of nearly 41,000 body images for use as stimuli. Researchers can make use of this established library of images along with the associated age, gender, and BMI information to create generalized body-perception experiments for large groups of participants. In addition, the AdoBMT software can be used to create individualized stimuli for each study participant given that a standardized source image (Figure 2.1) is available.

Which PCs and what amount of distortion should be used in future experiments? With respect to the different PCs, PC1 accounts for the greatest amount of variation in our model with a total of 82.9%. Although PC1 induces gross changes in all of the anthropometric measures, the single largest change is in the height of the body. As such, it is unlikely that PC1 will prove useful in future experiments. In contrast, PCs 2-8 account for variation ranging from 0.37-6.0%. These PCs account for much less of the variation in our model; yet, they also allow for greater variety in the combination of body parts that are manipulated. Although PC2 accounts for 6.0% of the variation, it does not appear to generate much in the way of physical changes in body size and shape. This is likely due to the fact that PC2 models changes in subject stance. Variation in subject stance would not be reflected in the anthropometric measures of Table 2.4 and thus, we see little in the way of changes in body shape and size.
Given the inherent difficulties with PCs 1 and 2, we will likely focus on the remaining PCs (i.e., 3-8) for use in future experiments. As indicated in Table 2.3, PCs 3-8 account for 0.37-2.5% of the variation in the model. In spite of these low values, one should note that use of these five PCs still results in substantial BMI changes. In fact, PC3 and 4 both induce an 11-point change in BMI when using a standard-deviation range from -0.8 to +0.8. These PCs appear to affect primarily body size and shape in the lower body; this may be particularly useful as prior studies have revealed that both adolescent males and females overestimate the size of their body parts including the waist, buttocks, and thighs (Bergstrom et al., 2000; Halmi et al., 1977).

We believe that the AdoBSD and AdoBMT represent novel morphing tools with three key advantages over many of the techniques currently in use (e.g., paper-and-pencil tools). These advantages include: (1) the use of high-fidelity digital images, (2) the use of adolescent bodies as the source, and (3) the use of a morphing procedure that accounts for natural covariations between individual body-parts and body views.

The use of a computerized-morphing technique is of particular importance as morphing allows the real-time production of individualized body-image stimuli, the flexibility to generate body images with a wider range of size, and the ability to quantify the scale of measurement. This enhances the use of these tools among clinical populations. For example, the morphing technique allows researchers to generate extremely large bodies for use with the obese and extremely thin bodies for use with anorexic patients. Although body morphing may appear quite complex, use of the image library will be made easy with online access and a simple online interface with which researchers can identify desired images using various parameters (i.e., gender, age, height, weight).
In the perceptual-realism experiment, we asked a group of healthy adult subjects to rate the "oddness" of both real and morphed images selected from the AdoBSD. We found linear distortion effects for PC4 and PC5, but not PC2; for the former two PCs, greater introduced distortion was associated with higher "oddness" scores. This effect indicates that adult subjects are able to detect subtle changes in body shape and size induced by morphing real images using these two PCs. The fact that PC2 failed to display any significant distortion effect for both front and side views is not surprising as this PC appears to model changes in subject stance. Consequently, PC2 will be excluded from future experiments. In contrast, PC4 will be selected as the morphing parameter of choice as it accounts for a greater percentage of the PCA model than PC5.

Another key finding lies in the relative degree of "oddness" of the morphed images when compared to the ratings of the real images. Healthy adult volunteers found body images distorted with 0.3 and 0.5 S.D. of PC4 and PC5 to be clearly more odd than the real images. It is clear that 0.5 S.D. of distortion is extreme; this level of distortion may, nevertheless, prove to be useful with clinical populations.

The primary goal of the behavioural experiment was to characterize the perceptual realism of the morphed images and, consequently, aide in the selection of appropriate morphing parameters. Nevertheless, analysis of mean scale scores revealed interesting effects of subject gender and image BMI with respect to the real body-images. In particular, females rated low-BMI images as significantly less odd than high-BMI images. Although these findings are not definitive in their ability to establish perceptual biases among the adults with respect to real body-perception, they are consistent with published studies investigating body dissatisfaction and ideal body-perception in both adolescents and adults. Numerous studies using various techniques have reported that
adolescent and adult females select an ideal body-size that is smaller or thinner than the perceived size of their real body (Brodie et al., 1994; Fallon et al., 1985; Fernandez et al., 1994; Kostanski et al., 2004; Rozin & Fallon, 1988; Sands & Wardle, 2003; Sands et al., 2004; Zellner, Harner, & Adler, 1989). In contrast, males have been found to select a larger or more muscular body-size as their ideal when compared to their perceived body-size (Brodie et al., 1991; Cohn et al., 1987; Pope, Jr. et al., 2000). Overall, some studies have also found that females report more body dissatisfaction when compared with males (Altabe et al., 1993; Kostanski et al., 2004). These findings, however, are often dependent on the BMI of the subject in question (Kostanski et al., 2004). Taken as a whole, these ideal-body and body-dissatisfaction studies support the results reported in the current study.

Our implicit experimental design has produced significant findings in spite of the fact that our volunteers were asked no explicit questions regarding the shape and size of the presented body-images. The very fact that the results appear to be in accordance with published results supports the validity of our tools.

Here we have described the development, characterization, and validation of a novel Adolescent Body-Shape Database and Adolescent Body-Morphing Tool. Although we have carefully described the development and biological characterization of the AdoBSD and AdoBMT, it would be of interest to compare this novel method with existing techniques by utilizing multiple techniques within a single study to explore the potential limitations or differences in an applied setting.

For future studies with healthy adolescents, the existing database of real and morphed images could be used such that participants would not have to pose for a source image but rather be simply matched to an existing child in the database. Once this
matching has been achieved, the real and morphed images of the AdoBSD child could be used as experimental stimuli. In order to facilitate the widespread use of this novel tool, we provide free access to the images used in the current study. This will allow an interested researcher to select and download real and morphed images for their studies. The image selection is facilitated by a matching algorithm: a researcher inputs participants’ age, height, and/or weight data and is provided with those AdoBSD images that best match those parameters. These tools may be accessed via the University of Nottingham Brain & Body Centre website (http://brainbody.nottingham.ac.uk/).

Although the AdoBSD and AdoBMT pertain to healthy adolescent children, the methodology of image acquisition, body-tagging, and body morphing can also be applied to other populations of interest such as obese adults or athletes. In order to recreate these tools for other specific populations, participants would have to pose for source pictures in similar bodysuits, and researchers would have to body-tag and individually morph these images.

Ultimately, future studies can now utilize these tools to explore the underlying cognitive processes of healthy adolescent body-perception, as well as clinical conditions such as obesity and eating disorders.

2.8 Acknowledgements

The authors would like to acknowledge the contributions of Louis Collins, Ph.D (McConnell Brain Imaging Centre, Montreal Neurological Institute), Zdenka Pausova, M.D. (Brain & Body Centre, University of Nottingham), and Rhonda Amsel, Ph.D (McGill University). Funding was provided by the Canadian Institutes for Health Research and the Santa Fe Institute Consortium.
Chapter 3

Self Body-Perception during Adolescence: Effects of Observer Sex and Body Mass Index

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In Preparation
3.1 Preface

In Chapter 2, we developed and characterized an adolescent-specific body-morphing tool with which we generated a digital library of morphed body-images that respect the natural covariations between adolescent body-parts. In Chapter 3, we describe the use of these morphed body-images in a behavioural study of visual body-perception.

Previous behavioural studies have failed to identify consistently whether adolescents are accurate in their perception of self body-size and shape. These conflicting results may be the result of various methodological limitations and inconsistencies. In Chapter 2, we addressed the fundamental issue of image realism with the development of the AdoBSD and AdoBMT. In Chapter 3, we will extend and improve upon previous behavioural studies by: (1) using realistic body-images of adolescents, (2) accounting for psychophysical anchor effects, (3) discriminating between sensory and nonsensory components of the perception of body size and shape, and (4) completing a rigorous statistical assessment of the accuracy of adolescent self body-size estimation and detection sensitivity to changes in body size. Chapter 3 describes the design and completion of a behavioural investigation of body size and shape perception among healthy adolescents, whereby we examined the potential modulatory influence of subject sex, age, and body mass index (BMI) on accuracy of estimation and detection sensitivity.
3.2 Abstract

The objective of this study was to examine, in healthy adolescents (10 to 18 years), the effects of sex, age, and body mass index (BMI) on the perception of one’s own body. Two hundred and fifty-six subjects (119 males, 137 females) were tested. Subjects were asked to indicate whether randomly-presented morphed body-images were larger or smaller than their own body. Subjects’ perception of their body size and their sensitivity to body morphing were associated with subject sex, age, and BMI. Males and females across the entire age range overestimated significantly their body size. Females, compared with males, overestimated the size of their bodies to a greater extent and showed greater sensitivity when detecting body morphing. Body-size (over)estimation increased with age. Sensitivity increased as a function of age and decreased as a function of BMI. Adolescents show a bias in the perception of their own bodies, which appears to vary as a function of sex, age, and BMI.
3.3 Introduction

The construct of body image has often been divided into two components: (1) a perceptual component of body size and shape and (2) an emotional or attitudinal component as an index of body satisfaction (Skrzypek et al., 2001; Slade, 1988). Among the adolescent population, body image has become an issue of growing importance since there have been reported increases in body dissatisfaction across the adolescent period (Davies et al., 1986; Gardner et al., 1999b; Kostanski et al., 2004; McVey et al., 2004), and in childhood and adolescent obesity (Chinn et al., 2001; Thompson et al., 2002; Tremblay et al., 2002), as well as a reported relationship between adolescence and eating disorders (Hsu, 1990; Lucas et al., 1991).

In order to evaluate adolescent body-perception, researchers have used the discrepancy between adolescents' real and perceived body-sizes. Measures of perceived body-size have been acquired among children and adolescents using various methods including: (1) self-report of subject weight (Brener et al., 2003; Elgar et al., 2005; Goodman, Hinden, & Khandelwal, 2000; Talamayan et al., 2006); (2) estimation of body-part widths using the visual size-estimation technique and adjustable light-beam apparatus (Bergstrom et al., 2000; Fabian et al., 1989; Halmi et al., 1977; Koff et al., 1978); (3) selection of a mock figure/silhouette as representative of an individual's perceived body-size (Rolland et al., 1996; Simeon et al., 2003); (4) adjustment of a distorted mirror or video body-image to an individual's perceived body-size (Brodie et al., 1994; Probst et al., 1995a); and (5) perceptual judgment of the relative size of distorted body-images with respect to an individual's real body-size (Gardner et al., 1999b). By comparing the real body-size with perceived body-size, a number of dependent variables can be calculated.
such as a body perception index (BPI; Slade et al., 1973) or a point-of-subject equality (PSE) value (Gardner et al., 1989b).

Given the inherent differences across these methodologies, it is not surprising that studies investigating adolescent body-size estimation often vary in their results. A significant distortion of body-size perception has been reported among children and adolescents in which they over- or underestimated the size of the entire body or various body parts (Bergstrom et al., 2000; Fabian et al., 1989; Halmi et al., 1977; Koff et al., 1978). But other studies concluded that adolescents have a relatively accurate perception of body size (Gardner et al., 1999b; Rolland et al., 1996).

We have recently developed a novel tool to assess body-size perception among adolescents (Aleong et al., 2007). First, we created an Adolescent Body-Shape Database (AdoBSD); the AdoBSD is composed of the digital images of 160 adolescents (9 to 17 years of age) and the height and weight of these subjects. Specific body tag-points were identified in these images and used in conjunction with principal components analysis (PCA) to identify natural covariations in body size and shape in this adolescent sample. Second, we developed an Adolescent Body-Morphing Tool (AdoBMT) that uses the isolated principal components to morph real body-images while respecting natural covariations in body size and shape, thereby producing morphed body-images for future experiments.

The goal of this study was to examine the role of sex, age, and body mass index (BMI) in the perception of one’s own body and one’s ability to detect subtle differences in body size as induced by image morphing. Previous studies of body perception have found that: (1) females report greater body dissatisfaction than males (Koff et al., 1990; Kostanski et al., 2004; Kostanski et al., 1998; Rosenblum et al., 1999; Thompson et al.,
1997; Wood et al., 1996), (2) females exhibit greater body-size overestimation compared with males (Bergstrom et al., 2000), (3) detection sensitivity increases significantly with age (Gardner et al., 1999b), and (4) obese or overweight individuals show poorer detection sensitivity compared with individuals of normal weight (Gardner et al., 1988a).

Based upon these findings, we hypothesized that: (1) female adolescents would show greater body-size biases and detection sensitivity than male adolescents, (2) body-size bias and detection sensitivity would increase with age during adolescence, and (3) adolescents with high BMI would show different biases and sensitivity compared with those with low BMI.

This study offers a novel perspective on body-size estimation among adolescents as we employed a newly-developed adolescent-specific tool that utilizes realistic morphed body-images that respect natural covariations in body shape and size. Using a computerized behavioural task, we established significant effects of sex, age, and BMI in self body-perception.

3.4 Materials and Methods

3.4.1 Subjects and Experimental Protocol

Subjects were recruited in three studies, two of which were conducted in Montreal, Quebec, Canada (Studies A and B) and one in Chicoutimi, Quebec, Canada (Study C). All experimental protocols were approved by the Research Ethics Board of the Montreal Neurological Institute and Hospital (Studies A, B, C) and the Research Ethics Committee of the Chicoutimi Hospital (Study C).
Study A was a targeted investigation of body perception among healthy adolescents. It examined the ability of adolescents to estimate the size of their own body and the body of a peer, as well as their perception of unfamiliar bodies. Study B is an ongoing longitudinal study of brain maturation and cognitive development during adolescence using a set of standardized neuropsychological tests, structural and functional magnetic resonance imaging (MRI), electroencephalography (EEG), and experimental behavioural tests. These behavioural tests include, but are not exclusive to, body-perception tasks. Study C is an ongoing cross-sectional study of the long-term effects of prenatal exposure to maternal cigarette smoking (PEMCS) on brain structure and function, psychosocial adaptation, academic achievement, and mental health using MRI, experimental tests of cognitive function, and assessments of cardiovascular and metabolic health (Pausova et al., 2007). All three studies included many procedures in addition to the self body-size perception task; however, for the purposes of this paper, only the behavioural results of the self body-size perception task will be considered.

Male and female subjects (10 to 18 years of age) were recruited from their respective communities using local advertising and targeted campaigns in elementary and high schools. In studies A and B (see below for details on Study C), prospective subjects were screened using a 31-question telephone screening interview and a medical questionnaire, both of which were completed by a parent, usually the biological mother. These screening tools examined: (1) the child’s language of schooling; (2) the pregnancy including in utero exposure to maternal cigarette smoking and alcohol; (3) the labour and birth of the child; (4) the child’s early medical history including behavioural, psychiatric, and neurological disorders; (5) the family’s medical history; and (6) the family socioeconomic status (e.g., family income). Exclusion criteria were: (1) premature birth
of the child; (2) medically significant complications during the pregnancy (e.g., gestational diabetes) or labour (e.g., pre-eclampsia, emergency caesarean section); (3) prenatal exposure to maternal cigarette smoking and/or extensive alcohol (i.e., > 70 mL of pure alcohol per week during the pregnancy); and (4) significant medical conditions during early childhood (e.g., neurological, psychiatric, behavioural).

Subjects were subsequently screened using the Child Behaviour Checklist (CBCL; Achenbach, 1991). The CBCL is a validated questionnaire for children between the ages of 6 to 18 years that provides an assessment on a series of Diagnostic and Statistics Manual of Mental Disorder (DSM-IV) subscales (e.g., affective, anxiety, somatic, attention deficit/hyperactivity problems). Any subject that scored in the clinical range on the summary subscales was excluded.

Subjects in Study C consisted of sib-pairs, approximately half of whom were exposed prenatally to maternal cigarette smoking. Unlike Studies A and B, all protocols in Study C were conducted in French. Subjects were recruited via local high schools. Upon initial contact, a research nurse completed a telephone screening interview with the mother to obtain information regarding: (1) basic demographics, (2) socioeconomic characteristics of the family, (3) medical history of the subjects, and (4) history of cigarette smoking, alcohol, and drug use during pregnancy. Exclusion criteria were: (1) a positive history for drug and/or extensive alcohol use during pregnancy; (2) a positive history for meningitis, malignancy, heart disease, and diabetes mellitus treated with insulin; and (3) severe mental illness and mental retardation. As PEMCS was used as an exclusionary criterion for studies A and B, PEMCS subjects from Study C were excluded from the analyses.
Following inclusion in the respective study, volunteers were asked to come to the Montreal Neurological Institute (Studies A and B) and the CEGEP de Jonquiere (Study C). Informed parental consent and participant assent were obtained prior to testing. In all studies, parents and adolescents received cash and a gift certificate, respectively, as compensation for their time and inconvenience.

A total of 256 subjects (119 males, 137 females) were tested using the self body-size perception task across all three studies. Subjects from Study C were all of French-Canadian origin while subjects from studies A and B were of mixed ethnicity. Scoring of the CBCL and examination of the parent medical questionnaire revealed that 13 subjects failed to meet the inclusion criteria for the study (i.e., received clinical scores on the CBCL or reported medically significant problems on the medical questionnaire); those subjects were excluded from all subsequent analyses. Sixty subjects from Study C were excluded due to PEMCS as all subjects from studies A and B were screened to be nonexposed to maternal cigarette smoking during pregnancy. One additional subject was excluded due to missing trials. Of the remaining 182 eligible subjects (86 males, 96 females), the mean age and BMI were: Males: 160.5 months [standard error of the mean (S.E.M.) = 2.7 months] and 20.4 kg/m^2 (S.E.M. = 0.5 kg/m^2); Females: 163.3 months (S.E.M. = 2.6 months) and 20.0 kg/m^2 (S.E.M. = 0.4 kg/m^2). Mean household incomes for male and female subjects were CAD 58631 (S.E.M. = 2741) and CAD 61250 (S.E.M. = 2410), respectively.

3.4.2 Self Body-Size Perception Task

Height and weight were measured in all adolescents. Each subject was matched to a child in the AdoBSD using the subject’s sex, height, weight, and BMI (Aleong et al.,
Subjects were matched to the AdoBSD child with the closest height, weight, and BMI using an unweighted Euclidean algorithm.

The AdoBSD refers to an image library containing the front and side body-images of 160 adolescents (Aleong et al., 2007). Variations in the body size and shape of database participants were modelled using PCA. Consequently, the real body-images of these 160 adolescents were distorted by manipulating the size and shape of various identified body-parts. Body parts were distorted using a preselected principal component (PC4) with predetermined levels of distortion as determined by the standard deviation (S.D.) of the mean of the PC (Aleong et al., 2007). This PC4-derived morphing involved predominantly the lower body region, in particular, the hips, thighs, and calves.

During testing, participants were seated approximately 60 cm from a computer screen. For subjects completing more than one body-perception task, the order of the body-related tasks was counterbalanced across all subjects within each sex. For the purposes of this paper, only the self body-size perception task will be discussed further.

The self body-size perception task was designed to assess the ability of a participant to estimate his/her real body-size when presented with morphed body-images. In order to investigate this question, we used the method of constant stimuli and a cumulative normal sigmoidal function that have been used in the context of body-size estimation previously (Fonagy et al., 1990; Gardner et al., 1996; Gardner et al., 1999b; Gardner et al., 1989b).

Morphed images of the AdoBSD child that best matched the participant were presented on screen. Body images were morphed using PC4 and four levels of morphing, namely, ± 0.1 and ± 0.3 S.D. of the mean of PC4. With respect to the real body-images, two smaller and two larger images were presented to a participant (four morphed images...
for each of the two views). The selection of PC4 and the two degrees of S.D. (i.e., 0.1, 0.3) were based upon the results of a previous validation study investigating the perceptual properties of the morphed body-images produced by the AdoBMT (Aleong et al., 2007).

The stimuli were displayed using the specialized software Presentation (Neurobehavioural Systems, San Francisco, CA). All subjects were given instructions, displayed on the computer screen, prior to the start of the experiment. The visual angle of the body-image stimuli ranged from 5.3° to 8.4° (height) and 2.8° to 4.5° (width). All 8 body images, 2 small and 2 large images for the front view and the same for the side view, were repeated 12 times for a total of 96 trials; images were presented in a random order. Subjects were asked to indicate whether each presented body-image was larger or smaller than their own body.

Trials were 3000 milliseconds (ms) in duration with an intertrial interval of 500 ms. Body images were randomly presented for 1000 ms followed by a blank screen for 1000 ms. Subjects could respond during the presentation of the body or the blank screen. Following an interstimulus interval of 500 ms, a fixation cross was presented on screen for 500 ms (Figure 3.1). Responses were recorded using a serial port button box (Study A) or USB mouse (Studies B and C).
Figure 3.1: Experimental task design. Morphed body-images were presented in front and side views while subjects were asked to indicate whether the presented image was larger or smaller than their perceived real body-size. (ISI = interstimulus interval; ITI = intertrial interval)

3.4.3 Statistical Analysis

All statistical analyses were completed using Matlab 6.5 (The Mathworks, Natick, Massachusetts) and SPSS 12.0 (SPSS Inc., Chicago, Illinois). Three dependent measures were analysed: (1) point-of-subject equality (PSE), (2) difference limen (DL), and (3) reaction time (RT). Subjects from the three studies were combined for all analyses.

The methodology used to calculate both PSE and DL has been described previously (Gardner et al., 1996; Gardner et al., 1989b). Briefly, for each image view and morphing level, a “too-wide” judgment score was calculated. This score reflected the percentage of “larger-than-me” responses for each condition. These scores were fitted against their respective morphing levels (i.e., -0.3, -0.1, +0.1, +0.3 S.D. of the mean of PC4) and the resulting sigmoidal curve was produced using a nonlinear least-squares curve-fitting
algorithm. From the best-fit curve for each subject, the PSE was identified as the morphing level for which the subject responded that the body was larger than him/her 50% of the time. The DL value refers to the amount of morphing required for detection of the morphed image 50% of the time. The DL value was calculated as the midpoint between the morphing levels at which 25% and 75% “larger-than-me” responses were obtained.

Subjects were excluded from the analysis based upon a number of factors including: (1) the quality of the calculated sigmoidal curve, (2) the goodness of fit between each subject’s data and the calculated sigmoidal curve, and (3) the goodness of match between the subject and the AdoBSD-derived body-image.

Given the importance of a sigmoidal curve for the determination of our dependent measures, PSE and DL, all curves were assessed for both front and side views. Subjects whose curves were inverted were excluded from all subsequent analyses. Similarly, an error term was used to evaluate the goodness of fit between the subjects’ data points and the calculated sigmoidal curve. Error terms were calculated separately for front and side views. The error terms were defined as the sum of squares difference value calculated between the real “too wide” data points and the selected sigmoidal curve. Outliers were defined as those subjects whose error terms exceeded the mean ± 3 S.D.

In order to evaluate the goodness of match between the subject and the AdoBSD-derived match, an AdoBSD matching-error quotient (AdoBSD MEQ) was used. Standardized age, height, weight, and BMI z-scores were calculated for all participants and all potential AdoBSD matches. We utilized z-scores to minimize any effect of unit scaling. Subjects and their respective AdoBSD matches were then placed in a
hypothetical n-dimensional space based upon these four criteria. The distance between these two points in space was calculated using the formula:

$$\text{AdoBSD MEQ} = \sqrt{(x_{\text{age}} - y_{\text{age}})^2 + (x_{\text{height}} - y_{\text{height}})^2 + (x_{\text{weight}} - y_{\text{weight}})^2 + (x_{\text{BMI}} - y_{\text{BMI}})^2}$$

where x and y represent the subject and AdoBSD match, respectively. Statistical outliers were identified as those individuals with an AdoBSD MEQ value greater than the mean ± 3 S.D. The AdoBSD MEQ value was used as an exclusionary criterion in order to ensure that subjects were comparing their bodies to a suitable likeness.

Based upon the aforementioned exclusion criteria, a total of 115 subjects (51 males, 64 females) were included in the front analyses. A total of 42 subjects were excluded based upon the quality of the PSE curve (INVERTED: 24 males, 18 females). Two additional subjects were excluded as a front PSE curve proved impossible to produce. Two subjects were excluded as statistical outliers for having front curve-fit-error values greater than the mean curve-fit-error ± 3 S.D. of the mean. Two subjects were excluded as AdoBSD MEQ outliers. An additional 18 subjects (12 females, 6 males) were excluded due to errors in the AdoBSD matching process. Finally, a check of the regression leverage statistics revealed one additional outlier case. The age and BMI distributions of the “front-image” population are detailed in Tables 3.1 and 3.2.

A total of 102 subjects (48 males, 54 females) were included in the side analyses after all exclusions. A total of 60 subjects were excluded based on the quality of the PSE curve (i.e., INVERTED: 32 males, 28 females). Two additional subjects were excluded as they failed to generate any sigmoidal curve. Two subjects were excluded as statistical
outliers based upon the side curve-fit-error (i.e., curve-fit-error greater than the mean ± 3 S.D.) and another subject was excluded as an AdoBSD MEQ outlier. Fourteen subjects (9 males, 5 females) were excluded due to errors in the AdoBSD matching process. Regression leverage statistics revealed one additional outlier case. The age and BMI distributions for the “side-image” population of subjects are described in Tables 3.1 and 3.2.

In the analysis of the PSE and DL results, we examined whether: (1) subject sex, age, and BMI played a role in subjects’ perception of body size and detection threshold and (2) subjects were accurate in their estimation of body size. In order to identify any potential trade-off between performance accuracy and reaction time, Pearson correlations were completed between PSE and DL values and RT, prior to the removal of any leverage statistic outliers. Multiple linear regression models were then created separately for the front and side views with PSE or DL as the dependent measure and subject sex, age, and BMI as model predictors. Multiple regression models were also calculated using all potential interactions as factors.

One-sample t-tests were conducted for variables of interest (i.e., sex, high and low age groups, BMI-derived weight groups) so as to determine whether subjects displayed an accurate perception of body size relative to their real body-size. If subject sex, age, and/or BMI proved to be significant predictors of PSE in the multiple regression models, t-tests were completed in order to identify whether group mean PSE values differed significantly from zero. A population mean of zero was defined as indication of perfect accuracy.
Table 3.1 – Subject age frequencies

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Table 3.2 – Subject body mass index (BMI) frequencies

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<td>14</td>
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<td>11</td>
<td>8</td>
</tr>
<tr>
<td>24-25.99</td>
<td>3</td>
<td>6</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>26-27.99</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>28-29.99</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>51</td>
<td>64</td>
<td>48</td>
<td>54</td>
</tr>
</tbody>
</table>
3.5 Results

3.5.1 Point-of-Subject Equality (PSE): Over/Underestimation of Body Size

Pearson correlations were conducted between front and side PSE and front and side RT, respectively. Pearson correlations failed to reveal any significant correlation between PSE and RT for either image view, \( p > 0.50 \). Multiple linear regression models with front- or side-image PSE as the dependent measure and subject sex, age, and BMI as predictors were then calculated.

Point-of-Subject Equality (PSE): Front View

The mean age and BMI of the included males and females in the front-image analysis are listed in Table 3.3. No significant relationship was detected between the regressors and front PSE \( [F(3,114) = 0.431, p > 0.7; \text{Table 3.4}] \). The interactions were also tested and the regression model was not significant \( [F(7, 114) = 0.196, p > 0.9] \).

Table 3.3 – Age and body mass index (BMI) - Mean values

<table>
<thead>
<tr>
<th></th>
<th>Front (n = 115)</th>
<th>Side (n = 102)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Males (n = 51)</td>
<td>Females (n = 64)</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>Standard Error</strong></td>
<td><strong>Mean</strong></td>
</tr>
<tr>
<td><strong>Age (months)</strong></td>
<td>163.16</td>
<td>3.45</td>
</tr>
<tr>
<td><strong>BMI (kg/m^2)</strong></td>
<td>20.58</td>
<td>0.43</td>
</tr>
<tr>
<td><strong>BMI (kg/m^2)</strong></td>
<td>20.51</td>
<td>0.49</td>
</tr>
</tbody>
</table>
Table 3.4 – Self body-size perception task - PSE regressions

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Front PSE (n = 115)</th>
<th>Side PSE (n = 102)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>S.E.</td>
</tr>
<tr>
<td></td>
<td>Zero-Order</td>
<td>Partial</td>
</tr>
<tr>
<td>Sex</td>
<td>-0.023</td>
<td>0.034</td>
</tr>
<tr>
<td>Age</td>
<td>0.000</td>
<td>0.001</td>
</tr>
<tr>
<td>BMI</td>
<td>-0.005</td>
<td>0.005</td>
</tr>
</tbody>
</table>

PSE = Point-of-Subject Equality; S.E. = Standard Error; BMI = Body Mass Index
Point-of-Subject Equality (PSE): Side View

The mean age and BMI of the included males and females in the side analysis are listed in Table 3.3. A significant relationship was observed between the regressors and side PSE \( F(3,101) = 4.856, p < 0.01 \), with the model accounting for 12.9% of the variance \( R = 0.360 \). No significant interactions were observed, \( p > 0.1 \). The effects of subject sex \( t(101) = 2.304, p < 0.05 \) and age \( t(101) = 2.757, p < 0.01 \) were significant (Table 3.4). Significant correlations were revealed between side PSE and subject sex \( r = 0.206, p < 0.05 \) and age \( r = 0.282, p < 0.01 \); thus, females and older subjects demonstrated higher PSE values compared with males and younger subjects, respectively. A significant correlation was also detected between two independent predictors, namely, age and BMI \( r = 0.265, p < 0.01 \).

Although the regressions establish the predictive qualities of subject sex, age, and BMI with respect to the PSE, they fail to address the issue of whether subjects’ perceived body-size is statistically different from their real body-size and, if so, whether the perceptual bias represents an over- or underestimation of body size. In order to address this question, we assumed that a PSE of zero represents perfect accuracy and then conducted one-sample t-tests based upon the results of the regression. In examining the sex effect revealed in the side-PSE regression, both males \( t(47) = 2.305, p < 0.05 \) and females \( t(53) = 6.365, p < 0.001 \) overestimated their body size (Figure 3.2a). The significant age effect revealed in the side-image regression was also explored by separating the population into two age groups based upon the median age (median = 158.85 months). One-sample t-tests revealed that both younger \( t(50) = 2.445, p < 0.05 \) and older \( t(50) = 6.285, p < 0.001 \) age groups overestimated significantly their real body-size (Figure 3.2b). Independent samples t-tests revealed that female subjects \( t(100) \)
and older subjects \[ t(100) = -2.212, p < 0.05 \] overestimated their real body-size to a greater extent than male subjects and younger subjects, respectively.

(a)

![Bar graph for gender comparison](image)

(b)

![Bar graph for age comparison](image)

Figure 3.2: Accuracy of perceived body-size: Side view. One sample t-tests were used to determine whether subjects perceived accurately their real body-size. (a) Both males and females overestimated significantly their body-size, \( p < 0.05 \). (b) Younger and older subjects also overestimated significantly their real body-size, \( p < 0.05 \). Females and older
subjects overestimated their body size to a greater extent than males and younger subjects, respectively, \( p < 0.05 \).

### 3.5.2 Difference Limen (DL): Detection Sensitivity

In examining the relationship between DL and RT, Pearson correlations revealed a significant relationship between front-image DL and front-image RT \([r = -0.180, p = 0.054]\). The correlation between side-image DL and side-image RT approached significance \([r = -0.171, p = 0.084]\). In light of these findings, RT was used as a covariate in the front- and side-DL regressions.

As with the PSE results, multiple linear regression models with front- or side-image DL as the dependent measure and sex, age, and BMI as predictors were completed. After subject exclusions and an examination of leverage statistics, the same subjects used in the front- and side-image PSE regressions were included in the front- and side-image DL regressions.

**Difference Limen (DL): Front View**

A significant relationship was revealed between the regressors and front-image DL \([F(4,114) = 3.423, p < 0.05]\), with the model accounting for 11.1% of the variance \((R = 0.333)\). The effects of subject sex \([t(114) = -2.475, p < 0.05]\) and subject age \([t(114) = -2.073, p < 0.05]\) were significant (Table 3.5). Lower DL values indicate higher detection sensitivity. An independent samples t-test revealed that females were significantly more sensitive to changes in body size in the front view \([t(113) = 2.174, p < 0.05; \text{Figure 3.3a}]\). A median age of 157.2 months was used to divide subjects into younger and older age groups. An independent samples t-test indicated that older subjects were more sensitive to
Table 3.5 – Self body-size perception task - DL regressions

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Front DL (n = 115)</th>
<th>Correlations</th>
<th>Side DL (n = 102)</th>
<th>Correlations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>S.E.</td>
<td>β</td>
<td>t</td>
</tr>
<tr>
<td>RT</td>
<td>0.000</td>
<td>0.000</td>
<td>-0.217</td>
<td>-2.366</td>
</tr>
<tr>
<td>Sex</td>
<td>-0.041</td>
<td>0.016</td>
<td>-0.224</td>
<td>-2.475</td>
</tr>
<tr>
<td>Age</td>
<td>-0.001</td>
<td>0.000</td>
<td>-0.194</td>
<td>-2.073</td>
</tr>
<tr>
<td>BMI</td>
<td>0.000</td>
<td>0.002</td>
<td>0.005</td>
<td>0.050</td>
</tr>
</tbody>
</table>

DL = Difference Limen; S.E. = Standard Error; BMI = Body Mass Index
changes in body size compared with younger subjects \[t(113) = 2.089, p < 0.05; \text{Figure 3.3b}\]. Significant correlations were found between: (1) front DL and sex \[r = -0.200, p < 0.05\], (2) front DL and age \[r = -0.148, p = 0.57\], and (3) age and BMI \[r = 0.246, p < 0.01\]. A significant three-way interaction between age, sex, and BMI was observed, but post-hoc tests of simple interactions produced no significant results.

![Graph showing detection sensitivity of body morphing](image)

Figure 3.3: Detection sensitivity of body morphing. (a) Independent samples t-tests
indicated that females showed greater sensitivity to body morphing than males in front and side views, p < 0.05. (b) Older subjects showed greater sensitivity to changes in body size in the front view only, p < 0.05.

**Difference Limen (DL): Side View**

A significant relationship was found between the model predictors and side-image DL [F(4,101) = 3.255, p < 0.05], with the model accounting for 11.8% of the variance (R = 0.344). The effect of subject sex [t(101) = -2.217, p < 0.05] was significant (Table 3.5). No interactions were significant, p > 0.1. Females showed greater sensitivity (i.e., lower DL) compared with males in the side view [t(100) = 2.222, p < 0.05, Figure 3.3a].

Significant correlations were observed between: (1) sex and side DL [r = -0.217, p < 0.05] and (2) BMI and side DL [r = 0.163, p = 0.050]. In contrast, no correlation was detected between age and side DL [r = -0.083, p > 0.2]. A correlation between age and BMI [r = 0.265, p < 0.01] was also found.

**3.6 Discussion and Conclusions**

In this study, we described significant effects of sex, age, and BMI on adolescent body-size estimation (PSE) and on detection sensitivity (DL) of body morphing. Female adolescents demonstrated greater overestimation biases and greater sensitivity to body morphing compared with male adolescents. Overestimation of body size increased with age. Detection sensitivity increased with age and decreased with larger BMI values. These findings clearly indicate that perceptual biases may not be exclusive to clinical populations (e.g., anorexia nervosa) but may be present in healthy individuals. It should
be noted that females exhibited both greater distortion sensitivity and increased perceptual bias. Most of these relationships were present only when subjects judged bodies presented in the side view.

Some existing studies of body-size estimation agree while others disagree with our findings. Our results are consistent with those reported in several studies that also found body-size overestimation during adolescence (Bergstrom et al., 2000; Halmi et al., 1977; Koff et al., 1978), greater female (versus male) overestimation (Bergstrom et al., 2000), slight sex differences in detection sensitivity (Fonagy et al., 1990; Gardner et al., 1990), and age-related increases in detection sensitivity between the ages of 6 to 14 years (Gardner et al., 1999b). Our results, however, are inconsistent with those of other studies that have reported accurate adolescent perception of body size (Gardner et al., 1999b; Rolland et al., 1996), no significant sex difference in detection sensitivity among adolescents (Gardner et al., 1999b) or adults (Gardner et al., 1996; Gardner et al., 1995; Gardner et al., 1987; Gardner et al., 1989b), and no differences in detection sensitivity between obese and control groups (Gardner et al., 1987; Gardner et al., 1989b).

We believe that our study contains a number of methodological differences that may explain some of the above discrepancies. Arguably, the tools used in the current study represent a methodological improvement in the assessment of adolescent body-size perception. The AdoBSD and AdoBMT allowed for the characterization of natural covariations in adolescent body-size and shape, and the morphing of adolescent bodies utilizing these age-specific variations. The age-specific body morphing enhances the realism of the presented images that, in turn, allows for a closer examination of the adolescent cognitive process. It is important to note that body-image stimuli were individually selected for each subject based upon his/her sex, height, weight, and BMI.
The effects of sex, age, and BMI described here are generally consistent with previous studies of body dissatisfaction and the perception of what represents an ideal body. In relating body-estimation biases with body dissatisfaction, a negative correlation has been found between body-distortion scores and body dissatisfaction, as measured by the Eating Disorder Inventory (EDI) in a clinical population (Pumariega et al., 1993). Adolescent body-size estimation studies have also described significant relationships between self body-size estimation and ideal body-size (Brodie et al., 1994) as well as body esteem (Gardner et al., 1999a). Postpubescent adolescent girls exhibited a significant negative correlation between perceived and ideal body-sizes; a larger perceived body-size was associated with a thinner ideal body-size (Brodie et al., 1994). In addition, body esteem was a significant predictor of body-size estimation scores with a negative correlation between the two factors; lower body-esteem was associated with overestimation (Gardner et al., 1999a).

Adolescent females have consistently expressed a desire to lose weight (Kostanski et al., 1998; Maloney et al., 1989; McVey et al., 2004; Rolland et al., 1997) and selected an ideal body-size smaller or thinner than their perceived body-size (Brodie et al., 1994; Gardner et al., 1999b; Parkinson et al., 1998; Tiggemann et al., 1998). Adolescent males, however, reveal a less consistent profile in that they have expressed a desire to either gain or lose weight (Furnham et al., 1998; Maloney et al., 1989; Middleman et al., 1998; Rolland et al., 1997), while selecting a larger, more muscular, or leaner ideal body-size (Cohn et al., 1987; Parkinson et al., 1998). This apparent conflict in male ideal-body selection and body dissatisfaction has been attributed to an experimental failure to discriminate between the male desire to lose adipose tissue or gain muscle tissue (McCabe et al., 2004). Underweight and overweight individuals appear to demonstrate
opposing trends in body dissatisfaction with underweight individuals wanting to gain weight and overweight individuals wanting to lose weight (Kostanski et al., 2004). Significant sex differences have also been observed, with adolescent females reporting greater body dissatisfaction than males (Koff et al., 1990; Kostanski et al., 2004; Kostanski et al., 1998; Rosenblum et al., 1999; Thompson et al., 1997; Wood et al., 1996).

In light of these reports, our findings of male and female overestimation of body size are not surprising. Given that adolescent females report high levels of body dissatisfaction and that their ideal body-size is typically smaller than their perceived real body-size, one could anticipate that, perceptually, they would overestimate their real body-size, as demonstrated here. Similarly, male overestimation may be a reflection of their dissatisfaction with their body size and their desire to achieve a leaner body through a loss of adipose tissue, thereby achieving a more muscular frame. In addition, previous reports of greater female body-dissatisfaction, when compared with males, are consistent with our results that show greater female, versus male, body-size overestimation and greater distortion sensitivity (i.e., lower DL).

Significant developmental trends have also been reported with general increases in body dissatisfaction through childhood and adolescence, particularly among females (Brodie et al., 1994; Davies et al., 1986; Eisenberg et al., 2006; Gardner et al., 1999b; Kostanski et al., 2004; Rosenblum et al., 1999; Salmons et al., 1988). Developmental trends in males remain unclear as some studies have shown body dissatisfaction to decrease or remain stable during adolescence (Gardner et al., 1999b; Rosenblum et al., 1999). This age effect may be influenced by changes inherent to pubertal maturation. For example, physical changes associated with puberty in females (i.e., increased body fat)
would result in a physique that is discordant with their desired ideal body-size thereby perpetuating body dissatisfaction, whereas physical changes associated with male puberty would lead to a convergence between their physical form (i.e., wider shoulder breadth, increased muscle mass) and their desired ideal-body (Koff et al., 1990).

In this study, a clear age effect was identified with respect to side PSE and front DL. The observed increase in side PSE found with increasing age is consistent with age-associated changes in body dissatisfaction and physical development, as described above. The negative relationship between front DL and age indicates that perceptual acuity increases with age, a finding that is consistent with previous work (Gardner et al., 1999b). In our study, the observed age effects were similar in female and male adolescents.

Our results are suggestive of a role for BMI in body perception. In the side PSE and DL analyses, no unique contribution of BMI was observed; however, any potential BMI effect may have been minimized by the age-BMI correlation that was detected. Nevertheless, a significant correlation between side DL and BMI was identified; the data indicate that sensitivity to morphing decreases with increasing BMI. Caution is required in interpreting these results as there were small effect sizes and a low number of overweight subjects in our sample. The existing literature remains mixed with respect to perceptual biases among overweight and/or obese individuals. Previous studies have reported: (1) overestimation of body size and reduced distortion detection sensitivity among obese adults (Gardner et al., 1988a), (2) no differences in body-size estimation and detection sensitivity when comparing adult obese and control groups (Gardner et al., 1989a; Gardner et al., 1987; Gardner et al., 1989b), or even (3) greater accuracy in body-size estimation by obese children compared with controls (Probst et al., 1995a). With the
growing trend of childhood and adolescent obesity, it is clear that further research must be conducted in order to establish whether perceptual biases exist.

Our profile of significant body-perception biases and differences in detection sensitivity may have implications for long-term health. In fact, body-perception biases and body dissatisfaction proved to be significant predictors of future eating problems (Attie et al., 1989; Gardner et al., 2000; Neumark-Sztainer et al., 2006). Subjects would have to be followed prospectively in order to determine whether adolescent body-size estimation biases are precursors to later adult pathology vis-à-vis eating behaviour.

In conclusion, we report significant biases in self body-size perception among healthy adolescents. Future work should include an examination of individual changes in task performance from early childhood through to the end of adolescence. Although we observed perceptual biases in healthy adolescents, the body-perception task can also be applied to clinical populations (e.g., anorexia nervosa and obesity) in order to determine whether clinical populations show similar or significantly different profiles compared with our healthy population.

3.7 Acknowledgements

Funding was provided by the Canadian Institutes for Health Research (R.A., T.P., Z.P.), McGill Major Fellowships (R.A.) and the Santa Fe Institute Consortium (T.P.). The authors would like to acknowledge the contributions of Chadwick Boulay for his assistance in the analysis and Simon Duchesne for his creation of the AdoBSD matching algorithm. Correspondence regarding this article should be addressed to T. Paus, Brain
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Chapter 4

Neural Correlates of Human Body-Perception

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In Preparation
4.1 Preface

In Chapter 3, we described relationships between sex, age, BMI and both accuracy of self body-size estimation and detection sensitivity to changes in body size and shape. Chapter 4 describes our attempt to identify the neural substrates of the perception of human body-size and shape as well as the correlates of the sex and BMI findings described in Chapter 3.

The literature clearly supports the notion that body representation is a complex multimodal construct involving various brain regions whose functional characteristics may depend on factors such as body identity (e.g., self versus other), body motion (e.g., static versus dynamic), and body structure (e.g., whole body versus body part). In order to generate a cohesive central representation of the body, whether it be of one's self or that of another, the brain must integrate neural signals derived from various sources including proprioceptive, tactile, and visual inputs. Clinical and experimental research have demonstrated that sensory deafferentation (Ramachandran & Hirstein, 1998) and manipulations in proprioceptive input (Ehrsson, Kito, Sadato, Passingham, & Naito, 2005; Lackner, 1988) may augment one's perception of self body-size and shape, likely involving regions in the parietal lobe. Little is known, however, about the visual processing of body size and shape. In light of the recent discovery of EBA and FBA as functional regions that are selectively responsive to visual images of the human body and body parts, one may ask whether these two regions are involved in the visual processing of the size and shape of human bodies. If so, one must also consider the role of EBA and FBA in the sex and BMI results reported in Chapter 3. In Chapter 4, we describe an fMR-adaptation study examining the sensitivity of EBA and FBA to images of human bodies.
of varying size and shape. The study also assessed the influence of the observer's sex and BMI on the perception of human bodies.
4.2 Abstract

The objective of this study was to investigate potential sex differences in the neural response to human bodies using functional magnetic resonance imaging (fMRI) carried out in healthy young adults (19 to 32 years; 11 males, 10 females). We presented human bodies (intact or scrambled) or faces (intact or scrambled) in a block-design experiment in order to identify body- and face-responsive regions of the brain, namely, extrastriate body area (EBA), fusiform body area (FBA), fusiform face area (FFA), and occipital face area (OFA). In a separate event-related “adaptation” experiment, carried out in the same group of subjects, we presented sets of four human bodies of varying body-size and shape. Varying levels of body morphing were introduced to assess the degree of morphing required for adaptation release. Analysis of blood oxygenation-level dependent (BOLD) signal in the block-design experiment revealed significant sex-by-hemisphere interactions in the EBA and FBA responses to human bodies. Women showed greater signal change in the right hemisphere compared with the left hemisphere for both EBA and FBA; men did not demonstrate any hemispheric differences. The BOLD response in right EBA was higher in women compared with men; this was not the case in left EBA. In the adaptation experiment, greater right hemisphere response was detected compared with the left hemisphere, across both regions. Greater right versus left hemisphere response for EBA and FBA was also identified among women, and not men. Both EBA and FBA demonstrated a significant release from adaptation; EBA showed greater sensitivity to a morphing level-dependent release of adaptation than FBA. In addition, observers’ body mass index (BMI) influenced the EBA hemispheric effects in both experiments. The results of the current study indicate that women show hemispheric asymmetry in their
perception of human bodies and that EBA is particularly sensitive to changes in the size of human bodies.
4.3 Introduction

Two key components of human body-image include one's perception of body size and shape as well as one's emotions or attitudes towards a body (Skrzypek et al., 2001; Slade, 1988). The study of human body-size perception, both of self and other individuals, has become particularly relevant with an increase in the prevalence of obesity (Ogden et al., 2006; Tremblay et al., 2002). In addition, significant overestimation of self body-size has been observed among patients with anorexia or bulimia nervosa compared with control groups (Cooper et al., 1988; Gardner et al., 1996; Slade et al., 1973).

Significant sex differences exist in the perception and evaluation of one's own body. Females, when compared with males, demonstrated: (1) greater overestimation of body size (Bergstrom et al., 2000; Aleong et al., unpublished results), (2) greater sensitivity to changes in body size (Aleong et al., unpublished results), and (3) greater dissatisfaction with their bodies (Kostanski et al., 2004; Rosenblum et al., 1999; Wood et al., 1996). Several studies have also reported sex differences in desired ideal body-size, with females and males describing their ideal body-size as, respectively, smaller or thinner (Ambrosi-Randic, 2000; Brodie et al., 1994; Tiggemann et al., 1998; Williamson et al., 2001) or larger, leaner, and more muscular (Cohn et al., 1987; Parkinson et al., 1998) than their real body-size. Such sex differences in body image appear to extend into the clinical domain, with the incidence of eating disorders being much higher in females than males (Currin, Schmidt, Treasure, & Jick, 2005; Hoek & van Hoeken, 2003; Lucas et al., 1991).

Based upon the above evidence of sex differences in body satisfaction and body-size perception, we decided to investigate the possible neural mechanism underlying sex
differences in the perception of variations in body size and shape. Previous lesion studies identified a number of brain regions that may play a role in the representation of the human body. Damage of the parietal cortex and/or temporal lobe have been associated with disorders of body representation including deficits in body-part localization (i.e., autotopagnosia; De Renzi et al., 1970; Denes et al., 2000; Felician et al., 2003; Semenza, 1988), neglect of one’s own body (Guariglia & Antonucci, 1992), deficits in producing or understanding the names of body parts (Dennis, 1976), and out-of-body experiences (Blanke et al., 2004).

Recently, a number of neuroimaging studies identified two regions in the extrastriate cortex that show greater response to human bodies and body parts compared with the neural response to objects, namely, the extrastriate body area (EBA) located in the lateral occipitotemporal cortex (Downing et al., 2006a; Downing et al., 2001; Downing et al., 2007; Peelen et al., 2005b; Taylor et al., 2007) and the fusiform body area (FBA) located in the lateral posterior fusiform gyrus (Peelen et al., 2005a; Schwarzlose et al., 2005). Transcranial magnetic stimulation (TMS) and functional magnetic resonance imaging (fMRI) studies implicated EBA in the local processing of static bodies, particularly that of individual body-parts (Taylor et al., 2007; Urgesi et al., 2004; Urgesi et al., 2007a; Urgesi et al., 2007b), as well as the processing of the human form, rather than the dynamic aspects, of biological motion (Downing et al., 2006b; Grossman et al., 2002). On the other hand, FBA may aide in the deciphering of body form through the configuration of individual parts into a whole body (Taylor et al., 2007).

Extrastriate body area has been consistently regarded as instrumental in the processing of the static body form. Our primary goal was to determine whether EBA is responsive to changes in the size of human bodies and whether this responsiveness
depends on the sex of the observer. In order to answer this question, we used an fMR-adaptation paradigm, which is based upon the premise that repeated presentation of an identical visual stimulus is associated with a reduction in the fMR signal in a given neuronal population (Buckner et al., 1998; Grill-Spector & Malach, 2001; Martin et al., 1995; Stern et al., 1996). Previous studies utilized fMR-adaptation to explore the effects of changes in size, position, illumination, and viewpoint on brain activity in object-selective regions (Ewbank, Schluppeck, & Andrews, 2005; Grill-Spector et al., 1999; Sawamura, Georgieva, Vogels, Vanduffel, & Orban, 2005; Vuilleumier, Henson, Driver, & Dolan, 2002). In our study, adaptation was induced through repeated presentation of an identical body. Recovery from adaptation was assessed after introducing subtle changes in body size and shape. If EBA or FBA neurons were size invariant then adaptation would be induced and remain unchanged following introduction of a difference in body size and shape. In contrast, if some of the EBA or FBA neurons were tuned to different body-sizes or shapes, then a significant recovery from adaptation would be observed.

The two primary goals of this study were to investigate whether: (1) EBA and FBA are responsive to changes in body size as determined by a release of the adaptation effect and (2) the neural response to human bodies and/or to changes in body size are different in men and women. We also took advantage of the natural variations in the body mass index (BMI) in our study population to investigate whether the neural response to human bodies varies as a function of the observer’s BMI. Based on our previous behavioural findings (Aleong et al., unpublished results), we predicted that individuals with high BMI would have lower EBA and FBA responses to bodies. Our results provide evidence of a significant relationship between observer sex, BMI, and the neural response to human
bodies, as well as evidence of EBA and FBA sensitivity to changes in body size and shape.

4.4 Materials and Methods

4.4.1 Subjects

All protocols were granted approval by the Ethics Committee of the University of Nottingham Medical School. Adult volunteers were recruited using advertisements posted at the University of Nottingham. Upon initial contact, subjects were screened for: (1) past and present diagnosis of a neurological, psychiatric, or behavioural disorder; (2) past or presently prescribed medications that may affect brain function (e.g., antidepressants); and (3) MRI contraindications.

Subjects who fulfilled the initial screening criteria were then asked to come to the laboratory for a single testing session lasting approximately three hours. Informed consent was obtained from all participants. Subjects then completed the computerized Quick Diagnostic Interview Schedule III-R (DISSI; Bucholz et al., 1991) that was used to screen participants for psychiatric, neurological, and behavioural disorders including anorexia nervosa, bulimia nervosa, depression, anxiety disorders, and substance abuse disorders. Upon completion, subjects viewed a brief practice session of the task used in the fMR-adaptation experiment.

A total of 21 subjects (11 males, 10 females) were tested but three subjects (2 males, 1 female) were subsequently excluded due to excessive head-motion during scanning (1 male), faulty MRI acquisition (1 male), and positive symptoms for an eating disorder (1 female). Of the remaining 18 eligible subjects (9 males, 9 females), the mean
age and BMI were: Males: 23.7 years [range = 19 to 32 years, standard error of the mean (S.E.M.) = 1.4 years] and 22.7 kg/m² (range = 18.7 to 30.4 kg/m², S.E.M. = 1.1 kg/m²); Females: 23.4 years [range = 20 to 27 years, S.E.M. = 0.9 years] and 20.7 kg/m² (range = 18.5 to 22.4 kg/m², S.E.M. = 0.4 kg/m²). Independent samples t-tests revealed no significant differences between males and females for either age or BMI, p > 0.1.

All eligible subjects were right-handed with the exception of one female volunteer and had normal or corrected-to-normal vision. None of the subjects tested positive for a psychiatric, neurological, or behavioural disorder as indicated by the DISSI.

4.4.2 Brain Imaging

All brain imaging was completed using a 1.5 T Phillips Achieva scanner (Eindhoven, Netherlands). An initial high-resolution T1-weighted structural image (matrix: 160 x 256 x 256; 1 mm³ voxels) was acquired for all subjects for localization and registration purposes with the functional data. A series of blood oxygenation-level dependent (BOLD) T2*-weighted gradient-echo, echo-planar images were then acquired. Two different functional acquisitions were used, respectively, for the rapid event-related design adaptation experiment and block-design experiment. All subjects completed the adaptation experiment first, followed by the block-design experiment, as we wished to maintain stimuli naiveté for body images among the participants for the primary adaptation experiment.

4.4.3 Rapid Event-Related Body-Size Adaptation Experiment

The aim of the adaptation experiment was to assess whether the body-responsive brain regions, EBA and FBA, were sensitive to changes in body size as determined by a
release of the adaptation effect. In addition, we wished to determine the level of body morphing required to trigger such a release of adaptation. Blood oxygenation-level dependent images were acquired using the following parameters: matrix size = 64 x 64; echo time = 50 milliseconds (ms); repetition time = 1500 ms; slice thickness = 4 mm; voxel size = 4 x 4 x 4 mm. A total of 159 19-slice frames were collected for each run after the gradients had reached steady state (28 min of total acquisition time).

Subjects were presented with a series of real and morphed body-images derived from the Adolescent Body-Shape Database (AdoBSD; Aleong et al., 2007). Real body-images (front view) were distorted by manipulating the size and shape of various identified body-parts using a preselected principal component (PC4) with levels of distortion defined by the standard deviation (S.D.) of the mean of the PC (Aleong et al., 2007). For the current study, PC4-derived morphing (e.g., 0.1, 0.2, 0.3, 0.4 S.D.) involved predominantly the hips, thighs, and calves.

The experiment involved a total of 364 trials divided into 7 separate runs, each run lasting 3.9 min. Trial order was randomized across all runs. A single trial consisted of four body images each presented for 200 ms with 100 ms of blank screen following each body image, for a total of 1200 ms. After each trial, one of three intertrial intervals (ITI), namely, 1800, 3300, or 4800 ms, was randomly used. During the ITI, a white fixation cross appeared on the screen (Figure 4.1). Body images were presented at a visual angle of approximately 2.5° x 5° (width x height).
Figure 4.1: Rapid event-related adaptation experiment. The experiment was conducted in order to establish whether EBA and FBA are sensitive to changes in body size and shape. Subjects were randomly presented with a total of 364 trials divided into 7 separate runs (i.e., 52 trials/run). Each trial consisted of four randomly-presented body-images conforming to one of seven testing conditions. For the identical and different conditions, four identical and different undistorted body-images were presented, respectively. For each of the four morphing conditions (e.g., 0.1 S.D., 0.2 S.D., 0.3 S.D., 0.4 S.D.), two real bodies and two morphed bodies were randomly presented. Subjects were instructed to indicate when they detected a rare change in image contrast.

To maintain the subject’s attention during the scan, we used an incidental task that required the subject to detect changes in the contrast of either a body or the fixation cross. These events occurred only rarely (3 out of 52 trials in a given run). The extent of the
change was demonstrated to subjects during the practice session. Images positive for a contrast change were dimmed by 30% using Adobe Photoshop 7.0 (Adobe Systems Incorporated, San Jose, CA). The dimmed body-image was randomly selected to be the second, third, or fourth image in a trial. Similarly, the fixation cross was dimmed for an equal duration as a body during a trial. Subjects were instructed to press, with the right hand, a button of an MRI-compatible button box as quickly as possible when they detected a change in image contrast.

A total of seven types of trials (conditions) were used in the adaptation experiment: (1) identical, (2) different, (3) 0.1-morphing, (4) 0.2-morphing, (5) 0.3-morphing, (6) 0.4-morphing, and (7) fixation. Fifty-two repetitions of each condition were included in the experiment for a total of 364 trials. The identical trial/condition consisted of four identical real body-images, all of the same AdoBSD adolescent. The different condition consisted of the real body-images of four different AdoBSD adolescents of the same sex. The four morphing conditions involved the presentation of two real body-images and two morphed body-images, all of a single AdoBSD adolescent (e.g., 2 real images + 2 0.4-morphed images). The order of the four morphed images was randomized within each trial. The fixation condition involved the continuous presentation of a fixation cross for the duration of the trial.

For the identical and morphed conditions, the images of 26 different adolescents from the AdoBSD (13 males, 13 females) were used. Male and female AdoBSD adolescents were age-matched (5 15-year-olds; 6 16-year-olds; 2 17-year-olds) and selected to reflect older age ranges so as to present the most adult-like images to our young adult volunteers. Body images were presented in the front view only. Given the positive range (S.D.) of morphing conditions, all morphed body-images were larger than
the real body-images. Each of the 26 AdoBSD adolescents was presented twice across the four morphing and identical conditions for a total of 260 trials.

For the different condition, the images of 18 different adolescents from the AdoBSD (9 males, 9 females) were used. Four AdoBSD adolescents (4 males or 4 females) were selected randomly for each trial. Again, males and females were age-matched (5 15-year-olds; 3 16-year-olds; 1 17-year-old). Unlike the adolescents used for the identical and morphed conditions, the height differences between the adolescents used for the different condition were controlled. In presenting the real images of these different AdoBSD adolescents, we wished to minimize the natural height differences between the AdoBSD images and, therefore, preselected the nine male and nine female AdoBSD adolescents so that the maximum height differential did not exceed the maximum height difference between a real body-image and 0.4-morph (i.e., 4% of height; 62 pixels). Fifty-two different trials were presented along with 52 fixation trials and 260 morphing/identical trials resulting in a grand total of 364 trials.

4.4.4 Block-Design Experiment

The goal of this experiment was to localize body-responsive (i.e. EBA and FBA) and face-responsive (i.e. FFA and OFA) cortical regions in each subject. The block-design experiment was completed for each subject during which BOLD images were acquired using the following parameters: matrix size = 64 x 64; echo time = 50 ms; repetition time = 3000 ms; slice thickness = 4 mm; voxel size = 4 x 4 x 4 mm. A total of 82 32-slice frames were collected after the gradients had reached steady state (total acquisition time of 25 min).
Subjects were presented with real body-images derived from the AdoBSD (Aleong et al., 2007), emotionally-neutral human faces derived from a set of standardized face stimuli by Schneider et al. (Erwin et al., 1992; Schneider, Gur, Gur, & Muenz, 1994), and scrambled versions of the same body and face stimuli. The experiment consisted of 6 runs with 16 blocks per run. Block types included human bodies, human faces, scrambled human bodies, scrambled human faces, and fixation. Within each run, block order was pseudo-randomized with three minisets of blocks, each set containing one block per condition followed by a final block of fixation. Within each miniset, the five blocks were randomized (Figure 4.2). Each 15-sec block was composed of 20 presentations of a given stimulus. Body, face, and scrambled images were each presented on the screen for 300 ms followed by a blank screen for 450 ms. During fixation, a cross was presented in the middle of the screen for 750 ms. All body images were presented at a visual angle of approximately 2.5° x 5° (width x height).

For the blocks of human bodies, 20 real body-images of adolescents from the AdoBSD (10 males, 10 females) were randomly selected from those AdoBSD adolescents ranging in age from 16 to 17 years. Similarly, for the blocks of human faces, 20 emotionally-neutral faces (10 males, 10 females) were randomly selected. The same 20 body images and 20 faces were used in all body and face blocks, but the image order was completely random within each block. The same body and face images were scrambled using a Matlab-based script (A. Mignault, personal communication, March 28, 2007) that divided an image into approximately 325 and 525 image squares, respectively (10 x 10 pixels per square). The location of the image squares were then randomly sorted creating a scrambled image. As in the adaptation experiment, an incidental task was used to
maintain subjects' attention. In this case, 2 of the 20 images (in each block) were randomly selected to contain a red circle in 1 of 9 physical locations overlaying the image. Subjects were instructed to press, with the right hand, a button when they detected the presence of the red circle.

Figure 4.2: Block-design experiment. The experimental protocol was used to identify body- (i.e., EBA, FBA) and face-responsive (i.e., FFA, OFA) brain regions for each subject. Subjects were presented with blocks of images representing five different conditions [i.e., bodies, scrambled bodies (s_bodies), faces, scrambled faces (s_faces), fixation]. Six runs were completed by each subject with each run consisting of 16 pseudo-randomized condition blocks. Each condition block was composed of 20 images of the respective condition. Subjects were asked to indicate when a red circle appeared on the screen.
4.4.5 Behaviour: Body Discrimination Task

After completion of the fMRI experiments, subjects were asked to perform a task outside the scanner. The design of the task was identical to the rapid event-related adaptation experiment. This time, however, subjects were asked to indicate whether the four bodies in a single trial were the same or different.

4.4.6 Body-Esteem Scale for Adolescents and Adults

All subjects completed the Body-Esteem Scale for Adolescents and Adults (BESAA; Mendelson et al., 2001), a 23-item questionnaire used to assess subjects' feelings about their appearance and weight, as well as subjects' body-esteem evaluations attributed to others through three separate subscales (i.e., BE-appearance, BE-weight, BE-attribution). A key advantage in the use of this scale is its differentiation between attitudes regarding general appearance and weight. Moreover, it attempts to assess the influence of others' opinions on self body-esteem. Previous use of the BESAA with adolescents and adults between the ages of 12 and 25 years revealed that females scored lower on the BE-Appearance and BE-Weight scales compared with males, an effect that was consistent across the entire testing age range (Mendelson et al., 2001).

4.5 Analysis

4.5.1 Image Processing

All images were first assessed for head motion and functional images underwent motion correction and low-pass filtering using in-house correction tools (fmr_preprocess.runs: R. Hoge, 1996). Images were then smoothed spatially using a 6-
mm full-width half-maximum Gaussian filter. All functional images were realigned to the third frame of the first run of the event-related experiment. All statistical analyses were completed using fmristat, a Matlab-derived (The Mathworks, Natick, Massachusetts) toolbox (Worsley et al., 2002). A model of each experimental design was created and convolved with a hemodynamic response function in order to generate experimental time-series (Glover, 1999).

For each run, a general linear model was used to calculate regression coefficients for every voxel. Multiple runs within task and within subject were combined using a fixed-effects analysis and subsequently transformed into a common standardized space (MNI 305; Collins, Neelin, Peters, & Evans, 1994). T-statistic maps were created for each individual for the following subtractions in our analysis of the block-design and event-related adaptation experiments: block-design – bodies minus scrambled bodies and faces minus scrambled faces; adaptation – different minus fixation, 0.1-morph minus fixation, 0.2-morph minus fixation, 0.3-morph minus fixation, 0.4-morph minus fixation, and identical minus fixation.

Individual multi-run t-statistic maps (bodies minus scrambled bodies) were then overlaid on individual high-resolution T1-weighted anatomical images in order to identify, in each subject, stereotaxic coordinates of EBA and FBA in standardized space. Localization of EBA and FBA was completed in accordance with previously published reports of relevant anatomy and mean coordinates in standardized space (Downing et al., 2006a; Downing et al., 2001; Peelen et al., 2005a; Peelen et al., 2005b; Schwarzlose et al., 2005; Spiridon et al., 2006), and through the use of established brain atlases (Duvernoy, 1999; Talairach & Tournoux, 1988). We anticipated EBA and FBA to be localized, respectively, within the lateral occipitotemporal cortex and lateral posterior
Similarly, FFA and OFA were identified from individual multi-run t-statistic maps (faces minus scrambled faces) overlaid on individual T1-weighted anatomical images, all in standardized space. Both regions were identified based upon previously reported anatomical locations and mean standardized coordinates (Kanwisher, McDermott, & Chun, 1997; McCarthy, Puce, Gore, & Allison, 1997; Puce, Allison, Asgari, Gore, & McCarthy, 1996; Puce, Allison, Gore, & McCarthy, 1995), and with the aide of brain atlases (Duvernoy, 1999; Talairach et al., 1988). We located FFA in the posterior fusiform gyrus and OFA in the lateral occipital cortex in the region of the inferior occipital sulcus or inferior occipital gyrus. A minimum t-value of 2.0 was used for the identification of EBA, FBA, FFA, and OFA in each subject. We used a less stringent criterion for localizing these regions in each subject in light of the strong responses in these regions in the group average t-statistic maps (see below) and the *a priori* nature of our hypotheses.

Once individual coordinates of EBA and FBA were identified from the block-design experiment, these peak voxel coordinates were used as the centre of a sphere (5 mm-radius) from which mean % change in BOLD signal was extracted from the comparisons of bodies minus scrambled bodies and faces minus scrambled faces for each subject. The same EBA and FBA coordinates determined in the block-design experiment were then used to extract % change in BOLD signal from each subject’s rapid event-related adaptation subtractions.

Average group t-statistic maps for the comparisons bodies minus scrambled bodies and faces minus scrambled faces were generated by combining the individual multi-run t-statistic maps transformed into standardized space using a mixed-effects model, as
defined by the multistat function in the fmristat toolbox. The group t-statistic maps were
thresholded at a p-value of 0.05 (t-statistic of 5.08) corrected for multiple comparisons.
Average group t-statistic maps were overlaid onto a group anatomical image that was
generated by averaging individual T1-weighted anatomical images previously
transformed into standardized space (MNI 305; Collins et al., 1994).

4.5.2 Percent BOLD Change Statistics

In the analysis of the block-design experiment, a repeated measures analysis of
variance (ANOVA) was completed with % change in BOLD signal as the dependent
variable, subject sex as the between-subjects factor, and cerebral hemisphere as the
within-subjects factor. Separate ANOVAs were completed for EBA, FBA, FFA, and
OFA. Repeated measures ANOVAs were also utilized to investigate % change in BOLD
signal extracted from the adaptation subtractions with % change in BOLD signal as the
dependent measure, subject sex as the between-subjects factor, and hemisphere and
condition (i.e., different minus fixation, 0.1-morph minus fixation, 0.2-morph minus
fixation, 0.3-morph minus fixation, 0.4-morph minus fixation, identical minus fixation) as
the within-subjects factors.

Given the significant age and BMI results described in our previous behavioural
study of adolescent body-perception (Aleong et al., unpublished results), we conducted
exploratory analyses using subject age and BMI as additional factors.

4.5.3 Behaviour: fMRI scanning

As described above, subjects were asked to indicate the presence of a red circle or a
change in image contrast during the block-design and event-related adaptation
experiments, respectively. In examining subject performance, we assessed the following dependent variables: (1) hits, (2) misses, (3) false positives, and (4) reaction time.

4.5.4 Behaviour: Body Discrimination Task

Subjects performed a same-different discrimination task after fMRI scanning was completed. Repeated measures ANOVAs were used to examine subject performance with the mean percentage of different responses or reaction time as the dependent measure, condition (i.e., identical, 0.1-morph, 0.2-morph, 0.3-morph, 0.4-morph, different) as the within-subjects factor, and subject sex as the between-subjects factor.

4.5.5 Body-Esteem Scale for Adolescents and Adults

Individual subscale scores were calculated as described previously (Mendelson, White, & Mendelson, 2003). Independent samples t-tests were conducted for each subscale with subject sex as the factor of interest.

4.6 Results

4.6.1 Bodies versus Scrambled Bodies

As shown in Figure 4.3, we observed a significantly higher BOLD response to human bodies, as compared with scrambled bodies, at several locations in the extrastriate cortex and fusiform gyrus (Table 4.1). These locations correspond to the previously identified extrastriate body area (Downing et al., 2006a; Downing et al., 2001; Peelen et al., 2005b) and fusiform body area (Peelen et al., 2005a; Schwarzlose et al., 2005).
Additional anatomical locations that showed significant BOLD response are listed in Table 4.1.

Table 4.1: Stereotaxic coordinates of significant regions of BOLD response for the comparison of human bodies versus scrambled human bodies

<table>
<thead>
<tr>
<th>Region</th>
<th>Hemisphere</th>
<th>Coordinates</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Middle occipital gyrus (EBA)</td>
<td>L</td>
<td>-43 -70 4</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>55 -68 -3</td>
<td>8.4</td>
</tr>
<tr>
<td>Fusiform gyrus (FBA)</td>
<td>L</td>
<td>-40 -55 -17</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>48 -51 -21</td>
<td>8.2</td>
</tr>
<tr>
<td>Superior parietal gyrus</td>
<td>L</td>
<td>-30 -60 51</td>
<td>5.5</td>
</tr>
</tbody>
</table>

In examining individual functional data, EBA was present in the left and right hemisphere for all 18 subjects. In contrast, left or right FBA were found in only 16/18 subjects. The EBA and FBA responses (i.e. % change in BOLD signal in the bodies-minus-scrambled-bodies subtraction) were quantified in each subject. Repeated measures ANOVAs revealed significant hemisphere-by-sex interactions for EBA [F(1,16) = 6.8, p < 0.05] and FBA [F(1,12) = 7.2, p < 0.05]. Simple main effects analysis revealed that females showed greater response in the right than left hemisphere for both EBA and FBA, p < 0.01 (Figure 4.3a, b). In addition, females demonstrated greater response than males in the right EBA, p = 0.05.
Figure 4.3: Extrastriate Body Area (EBA) and Fusiform Body Area (FBA) response to human body-images. Average group t-statistic maps for the comparison of bodies minus scrambled bodies revealed significant BOLD response in bilateral EBA and FBA. Percent change in BOLD signal was extracted from a sphere (5 mm-radius) centred at each subject’s EBA and FBA coordinates for the subtraction of bodies minus scrambled bodies. Repeated measures ANOVAs were completed separately for EBA and FBA. Significant sex-by-hemisphere interactions were detected for both EBA (a) and FBA (b), p < 0.05. Females demonstrated a greater right than left hemisphere response for EBA and FBA, p < 0.01, as well as greater right EBA response compared with males, p = 0.05.

Exploratory analyses revealed no significant main effect or interaction effects with
respect to subject age for EBA or FBA, $p > 0.1$. No main effect of subject BMI was found with respect to the BOLD response in EBA or FBA, $p > 0.2$. A significant interaction between hemisphere and BMI, however, was identified for EBA [$F(1,14) = 7.9$, $p < 0.05$]. Further examination of the data revealed that subjects with relatively large BMI were generally male. In order to address this potential confounding effect of subject sex, the above BMI analyses were repeated separately for male and female groups. For males, a significant interaction between hemisphere and BMI was identified [$F(1,6) = 9.4$, $p < 0.05$]. Separation of the male subjects into mean BMI $- 1$ S.D., mean BMI, and mean BMI $+ 1$ S.D. groups and pairwise comparisons revealed greater right versus left EBA response for the mean BMI $- 1$ S.D. group only, $p < 0.05$ (Figure 4.4a). For females, the interaction between hemisphere and BMI was not significant [$F(1,6) = 3.4$, $p = 0.1$; Figure 4.4b].
Figure 4.4: Influence of observer body mass index on the perception of human bodies. Observer BMI interacted significantly with cerebral hemisphere for males in the block-design experiment (a) and females in the adaptation experiment (d). Females with higher BMI showed no hemispheric asymmetry in EBA response, p > 0.6, while males with low BMI did show greater right than left EBA response, p < 0.05.
4.6.2 Faces versus Scrambled Faces

As shown in Figure 4.5, we found significant BOLD response to human faces, as compared with scrambled faces, in the fusiform gyrus and lateral inferior occipital gyrus and/or inferior occipital sulcus (Table 4.2). These locations for FFA and OFA are consistent with previous reports (Kanwisher et al., 1997; McCarthy et al., 1997; Puce et al., 1996; Puce et al., 1995). Significant activity was also detected in the middle occipital gyrus and amygdala (Table 4.2).

Table 4.2: Stereotaxic coordinates of significant regions of BOLD response for the comparison of human faces versus scrambled human faces

<table>
<thead>
<tr>
<th>Region</th>
<th>Hemisphere</th>
<th>Coordinates</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fusiform gyrus (FFA)</td>
<td>L</td>
<td>-33 -44 -25</td>
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</tr>
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<td></td>
<td>R</td>
<td>48 -59 -21</td>
<td>8.9</td>
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<tr>
<td>Inferior occipital gyrus/Inferior occipital sulcus (OFA)</td>
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<td>-37 -79 -11</td>
<td>6.5</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>49 -76 -10</td>
<td>7.2</td>
</tr>
<tr>
<td>Middle occipital gyrus</td>
<td>L (anterior)</td>
<td>-48 -46 3</td>
<td>5.9</td>
</tr>
<tr>
<td></td>
<td>L (posterior)</td>
<td>-44 -71 5</td>
<td>6.0</td>
</tr>
<tr>
<td>Amygdala</td>
<td>L</td>
<td>-13 -4 -17</td>
<td>5.3</td>
</tr>
</tbody>
</table>
Figure 4.5: Fusiform Face Area (FFA) and Occipital Face Area (OFA) response to human face-images. Average group t-statistic maps for the comparison of faces minus scrambled faces revealed significant bilateral BOLD response in FFA and OFA. Repeated measures ANOVAs were completed separately for FFA (a) and OFA (b). A significant sex-by-hemisphere interaction was detected for OFA only, with females showing greater right OFA response compared with left OFA, p < 0.05.

In examining individual functional data, right FFA and OFA were present in all 18 subjects. One subject failed to demonstrate either left FFA or OFA. In the case of FFA, a repeated measures ANOVA of the individual BOLD responses revealed no significant
effects of sex, hemisphere, or their interaction, p > 0.1 (Figure 4.5a). In contrast, for individual OFA values, an ANOVA revealed a significant interaction between sex and hemisphere [F(1,15) = 5.6, p < 0.05]. Simple main effects analysis indicated that females showed greater response in the right than left hemisphere, p < 0.05 (Figure 4.5b). For FFA and OFA, subject age and BMI were not related to the BOLD signal across hemispheres, p > 0.3. In addition, no significant interactions between age and BMI with hemisphere were detected, p > 0.6.

4.6.3 Adaptation Effects

We used the individual coordinates of EBA and FBA, identified in the block-design experiment, to quantify the BOLD response in each subject’s multi-run t-statistic maps obtained for each of the adaptation-related subtractions. Repeated measures ANOVAs revealed a significant main effect of hemisphere for both EBA [F(1,16) = 6.5, p < 0.05; Figure 4.6a] and FBA [F(1,12) = 6.4, p < 0.05; Figure 4.7a], with the right hemisphere showing greater BOLD response than the left hemisphere. This is consistent with the findings obtained in the block-design experiment, as described above. Although the sex-by-hemisphere interactions for EBA [F(1,16) = 1.3, p = 0.3] and FBA [F(1,12) = 3.2, p = 0.1] were not significant, post-hoc analyses were conducted in light of the strong sex-by-hemisphere interactions observed in the block-design experiment. Post-hoc comparisons with Bonferroni correction revealed that females, and not males, showed greater BOLD response in the right versus left hemisphere in both EBA and FBA, p < 0.05 (Figures 4.6b, 4.7b).

A significant effect of condition was also identified in both EBA [F(5,80) = 23.1, p < 0.001] and FBA [F(5,60) = 8.8, p < 0.001]. Pairwise comparisons with Bonferroni
correction for multiple comparisons revealed a clear adaptation effect in both regions; significant differences between the different-fixation and the identical-fixation conditions were observed, p < 0.001. EBA also showed a greater sensitivity to changes in body size and shape: no significant differences were detected between the identical, 0.1, and 0.2 conditions, p > 0.9. The BOLD signal at the 0.3 and 0.4-morphing conditions was higher relative to the 0.2 and 0.1 conditions, p < 0.01, but lower relative to the different condition, p < 0.01. These progressive increases in BOLD response and significant signal recovery at the 0.3-morphing level reflect a clear sensitivity to small changes in the size and shape of the body images (Figure 4.6c).

In the case of FBA, adaptation effects were also observed (Figure 4.7c). A recovery from adaptation was identified at the 0.3-morphing level, p < 0.05. No significant differences were identified between the identical, 0.1, and 0.2 conditions, p > 0.9. The BOLD signal at the 0.3 and 0.4-morphing conditions did not differ significantly from the 0.1 and 0.2 conditions, p > 0.06, nor from the different condition, p > 0.4, indicating that FBA showed reduced sensitivity to body-size changes when compared with EBA.

A main effect of subject age was found across hemispheres and morphing conditions for EBA only [F(1,14) = 7.3, p < 0.05]. Subject BMI was also related to the BOLD response across hemispheres for both EBA [F(1,14) = 4.6, p < 0.05] and FBA [F(1,10) = 5.5, p < 0.05]. A significant hemisphere-by-BMI interaction was found for EBA only [F(1,14) = 5.0, p < 0.05]. As described for the block-design experiment, separate BMI analyses were conducted for males and females.
Figure 4.6: Extrastriate Body Area (EBA) adaptation results. Percent change in BOLD signal was extracted from EBA coordinates derived from the block-design experiment for
each subject. A repeated measures ANOVA revealed significant main effects for brain hemisphere (a), $p < 0.05$, and body-morphing condition (c), $p < 0.001$. Greater right EBA BOLD response was identified compared with left EBA, $p < 0.05$. Post-hoc analyses revealed that females, but not males, showed a greater right versus left EBA response (b), $p < 0.05$. A significant adaptation effect was observed as evidenced by a significant reduction in BOLD signal for the identical-fixation condition compared with the different-fixation condition, $p < 0.001$. A significant recovery from adaptation was also found at the 0.3 S.D.-morphing level, indicating that EBA was sensitive to changes in body size and shape.
Figure 4.7: Fusiform Body Area (FBA) adaptation results. Percent change in BOLD signal was extracted from FBA coordinates derived from the block-design experiment for
each subject. A repeated measures ANOVA revealed a significant main effect of hemisphere (a) with greater right versus left FBA response, $p < 0.05$. Post-hoc analyses revealed that females, but not males, showed a greater right versus left FBA response (b), $p < 0.05$. A significant main effect of condition (c) was also found, $p < 0.001$. A significant reduction in BOLD signal was detected upon presentation of identical bodies when compared with the presentation of different bodies, $p < 0.001$. A recovery from adaptation was found at the 0.3 S.D. level, $p < 0.05$.

For females, a significant interaction was identified between hemisphere and BMI $[F(1,6) = 7.6, p < 0.05; \text{Figure 4.4d}]$. Examination of mean BMI − 1 S.D., mean BMI, and mean BMI + 1 S.D. groups revealed greater right versus left EBA response for the mean BMI − 1 S.D., $p < 0.01$, and mean BMI, $p < 0.05$, groups. These findings are consistent with the block-design experiment findings, whereby individuals with larger BMI failed to show hemispheric asymmetry in the EBA response to human bodies.

For males, a significant three-way interaction was identified between hemisphere, morphing condition, and BMI $[F(5,30) = 2.6, p < 0.05; \text{Figure 4.4c}]$. Post-hoc analyses were conducted for the mean BMI − 1 S.D., mean BMI, and mean BMI + 1 S.D. groups. Pairwise comparisons revealed that greater right versus left EBA response was found for the 0.4-morph condition for the mean BMI − 1 S.D. group only, $p < 0.05$.

4.6.4 Behaviour: fMRI scanning

Mean performance scores for the red circle and image-contrast detection tasks are listed in Table 4.3. Independent samples t-tests revealed no significant differences
between males and females for any performance variable for both the red circle (p > 0.4) and image-contrast (p> 0.2) detection tasks.

Table 4.3: Functional magnetic resonance imaging - Behavioural results

<table>
<thead>
<tr>
<th></th>
<th>Block-Design Experiment</th>
<th>Adaptation Experiment</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Males</td>
<td>Females</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>S.E.M.</td>
</tr>
<tr>
<td>Hits</td>
<td>98.6</td>
<td>0.4</td>
</tr>
<tr>
<td>Misses</td>
<td>1.5</td>
<td>0.4</td>
</tr>
<tr>
<td>False Positives</td>
<td>0.05</td>
<td>0.02</td>
</tr>
<tr>
<td>Reaction Time (ms)</td>
<td>443.0</td>
<td>18.1</td>
</tr>
</tbody>
</table>

4.6.5 Behaviour: Body Discrimination Task

Two performance variables were examined to assess subjects’ performance on the body-discrimination task conducted outside the scanner. These variables included mean reaction time and the mean percentage of “different” responses for each condition. Separate repeated measures ANOVAs revealed significant main effects of condition for both reaction time \([F(5,80) = 13.0, p < 0.001]\) and percent “different” responses \([F(5,80) = 171.2, p < 0.001]\). Pairwise comparisons with Bonferroni correction for multiple comparisons revealed significant differences between conditions for mean percent “different” responses with an increasing number of “different” responses with increasing
degree of morphing, $p < 0.01$ (Figure 4.8a). Similarly, pairwise comparisons demonstrated that the mean reaction times for the 0.4-morph and different conditions were significantly lower than for the other conditions, $p < 0.05$ (Figure 4.8b). We found no effect of sex or sex-by-condition interaction, $p > 0.2$.

![Graph and Table](image)

Figure 4.8: Body discrimination behavioural results. Subjects were asked to perform a behavioural task following fMRI acquisition. The design of the behavioural task was identical to the fMR-adaptation experiment, but subjects were asked to indicate if the four bodies presented in a single trial were the same or different. Two dependent measures were assessed, namely, the percentage of “different” responses (a) and mean reaction time (b) for each body condition. Repeated measures ANOVAs revealed significant main
effects of condition for % different responses, p < 0.001, and reaction time, p < 0.001. An increasing number of “different” responses were identified with increasing body morphing, p < 0.01. Subjects also responded faster with the 0.4 S.D. and different body-conditions, p < 0.05.

4.6.6 Body-Esteem Scale for Adolescents and Adults

Mean values of the three subscales of the BESAA are listed in Table 4.4. Independent samples t-tests indicated a significant effect of sex for BE-appearance [t(16) = 3.5, p < 0.01] and BE-weight [t(16) = 2.2, p < 0.05] with females demonstrating significantly lower body-esteem than males.

Table 4.4: Body-Esteem Scale for Adolescents and Adults scores

<table>
<thead>
<tr>
<th></th>
<th>Males</th>
<th>females</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S.E.M.</td>
</tr>
<tr>
<td>BE-Appearance</td>
<td>29.3</td>
<td>1.5</td>
</tr>
<tr>
<td>BE-Weight</td>
<td>24.2</td>
<td>1.0</td>
</tr>
<tr>
<td>BE-Attribution</td>
<td>11.8</td>
<td>0.8</td>
</tr>
</tbody>
</table>

4.7 Discussion and Conclusions

Our study revealed that female, but not male, observers exhibited greater response
in the right than left hemisphere to images of human bodies for both EBA and FBA. This finding was obtained in both block-design and adaptation experiments. Extrastriate body area and FBA showed a clear recovery from adaptation following the introduction of small changes in body size and shape, thus arguing in favour of a fine-grained neural mechanism underlying the perception of human bodies involving these two regions. Extrastriate body area showed greater sensitivity to human bodies compared with FBA, as indicated by the ability of EBA to discriminate between 0.3 and 0.4 conditions relative to the different condition. Observers’ BMI also modulated the hemispheric effects in both experiments; females with larger BMI showed no difference in the BOLD response between left and right EBA while males with low BMI did show hemispheric asymmetry in EBA response.

It is important to note that the above results were obtained without asking the subject to make any explicit judgments about the bodies; incidental tasks were used instead to ensure participants’ attention during the presentation of the stimuli. With no differences in subject performance having been observed, we conclude that attention was sufficiently maintained by both sexes.

A key finding of our study is the sex difference in the hemispheric asymmetry of EBA and FBA responses to images of human bodies. Overall, the presence of such hemispheric asymmetry is consistent with a number of previous studies. Note, however, that none of the studies mentioned below examined possible sex differences in brain asymmetry. Previous fMRI studies have described greater consistency in the localization of right EBA (Downing et al., 2001), greater selectivity for bodies in right EBA compared with left EBA (Downing et al., 2006a), and greater whole-body selectivity in the right hemisphere compared with the left hemisphere (Downing et al., 2007). Distortion of the
body form, such as displacing an arm or leg onto the neck, resulted in a greater reduction of the N1 amplitude recorded over the right versus left hemisphere (Gliga et al., 2005).

Hemispheric differences have also been described in patients with brain damage and patients with eating disorders (Frassinetti, Maini, Romualdi, Galante, & Avanzi, 2008; Smeets & Kosslyn, 2001; Uher et al., 2005). Patients with lesions in the right hemisphere showed significantly greater deficits in self body-part matching when compared with those with left-hemisphere lesions and with controls (Frassinetti et al., 2008). Patients with anorexia nervosa showed faster reaction times to larger body-image distortions when presented to the left versus right hemisphere and slower reaction times to thinner body-image distortions when presented to the left versus right hemisphere (Smeets et al., 2001). In response to real and distorted body-shapes, healthy women and women with eating disorders showed stronger and/or more extensive BOLD response in the right, compared with left, EBA (Uher et al., 2005).

Some clues as to the functional significance of greater right EBA and FBA engagement may be derived from face-perception studies, which have described right hemisphere dominance in the FFA response to faces (Kanwisher et al., 1997; McCarthy et al., 1997; Puce et al., 1996). A case has been made regarding the potential similarities between the perception of human faces and bodies, as both types of stimuli are biologically important classes of objects that show behavioural inversion effects (Farah et al., 1995; Reed et al., 2003; Reed et al., 2006; Valentine, 1988; Yin, 1969), and are processed in category-selective brain regions (Downing et al., 2006a; Downing et al., 2001; Downing et al., 2007; Kanwisher et al., 1997; McCarthy et al., 1997; Peelen et al., 2005a; Puce et al., 1996; Puce et al., 1995; Schwarzlose et al., 2005). Hemispheric differences in face perception (i.e., greater right than left hemisphere) may be explained,
in part, by face configuration and familiarity. The right FFA showed greater response when matching whole faces compared with face parts, whereas the left FFA demonstrated the reverse pattern (Rossion et al., 2000). In addition, right FFA and OFA exhibited greater levels of activity for unfamiliar versus familiar faces (Rossion, Schiltz, & Crommelinck, 2003). Note, however, that we did not observe hemispheric asymmetry in FFA response but did identify greater right than left OFA response.

The role of configuration and familiarity, as described in face perception, may also be relevant for hemispheric differences in body perception. For example, EBA showed a gradual increase in selectivity as a function of the number of body parts displayed, indicating that EBA may code for body parts more so than for the whole body (Taylor et al., 2007). The right EBA dominance that we observed in women may, therefore, be representative of sex differences in the relative sensitivity to individual body-parts.

All body-image stimuli utilized in the block-design and adaptation experiments were of unfamiliar bodies presented from an allocentric viewpoint. Previous studies reported a greater right EBA response to allocentric body-images when compared with egocentric body-images (Chan, Peelen, & Downing, 2004; Saxe et al., 2006). Left EBA, in contrast, failed to distinguish between the two image perspectives (Chan et al., 2004; Saxe et al., 2006). Thus, greater right EBA activity may be related, in part, to the viewpoint of the bodies used.

The more robust response to human bodies present in right EBA in women, but not men, may represent a neural substrate of the sex differences in the perceptual and cognitive processes described previously. For example, we found greater overestimation of body size and greater detection sensitivity to changes in body size when comparing women with men (Aleong et al., unpublished results). Others found that women, but not
men, show an increased bias in identifying bodies as fatter than their real body-size when presenting body images in the left visual field (Mohr, Porter, & Benton, 2007). Previous neuroimaging studies of sex differences in the response to human bodies focused mostly on emotional processing and used explicit tasks involving words related to body image (Shirao, Okamoto, Mantani, Okamoto, & Yamawaki, 2005) or images of bodies (Kurosaki et al., 2006). In these studies, brain regions such as the amygdala and prefrontal cortex showed a differential response in women and men (Kurosaki et al., 2006; Shirao et al., 2005).

The results of our rapid event-related experiment also support the proposal that EBA and FBA may be involved in the neural processing of human body-size, as we observed significant adaptation effects and, most importantly, recovery from adaptation with subtle changes in body size. We found that EBA was more sensitive to changes in the size and shape of human bodies since EBA, and not FBA, was able to distinguish between the 0.3, 0.4, and different conditions.

Sensitivity to object size has been explored previously in object-specific brain regions including monkey inferotemporal complex (Desimone et al., 1984; Ito, Tamura, Fujita, & Tanaka, 1995; Logothetis, Pauls, & Poggio, 1995; Sato, Kawamura, & Iwai, 1980; Schwartz, Desimone, Albright, & Gross, 1983) and human lateral occipital cortex (LOC) and FFA (Ewbank et al., 2005; Grill-Spector et al., 1999; Malach et al., 1995; Malach, Grill-Spector, Kushnir, Edelman, & Itzchak, 1998; Sawamura et al., 2005; Vuilleumier et al., 2002). Although previous studies have reported a mixed pattern of size invariance in LOC, particularly in response to faces, we described a clear sensitivity to human body-size in the body-responsive regions of EBA and FBA. This specific divergence in size variance suggests that human bodies may be a special category of
objects for which a sensitivity to body size is necessary. Processing of body size in EBA and FBA may permit greater efficiency in interacting with the external environment through the positioning of one’s body relative to another body or the assessment of external threats. In support of this idea, various animal species (e.g., crayfish, crabs) use relative differences in body size as a criterion when deciding whether to engage in physical conflict; when the relative body-size difference between combatants is large, the likelihood of physical conflict is reduced and interactions are less intense and of shorter duration (Gali-Muhtasib & Smith, 1998; Jennions & Backwell, 1996; Morrell, Lindström, & Ruxton, 2005; Pratt, McLain, & Lathrop, 2003; Smith, Huntingford, Atkinson, & Taylor, 1994).

The different recovery patterns demonstrated by EBA and FBA in the adaptation experiment are also consistent with previous neuroimaging results describing differential responses of EBA and FBA as a function of the amount of body figure visible to the observer (Taylor et al., 2007). We described a greater EBA sensitivity to changes in body size when compared with FBA. Similarly, Taylor and colleagues described a gradual increase in response by EBA as the amount of body visible increased; FBA showed a more step-like increase in response when torsos were presented (Taylor et al., 2007). The authors proposed that EBA is biased towards the representation of individual body-parts and shows greater selectivity for individual body-parts compared with FBA, which preferentially represents larger portions of the human body (Taylor et al., 2007). In light of this hypothesis, our results may be indicative of EBA processing of changes in the body size of individual parts, whereas FBA may process larger scale changes in body size.
One additional finding was that of a significant interaction between observer BMI and EBA response in both experiments. This finding should be interpreted with caution due to the low variability in BMI among our participants and the relatively low number of subjects. Nevertheless, females with higher BMI showed no hemispheric asymmetry in the BOLD response of EBA. This result is consistent with our previous behavioural study in which we observed a negative correlation between subject BMI and detection sensitivity for body-morphing changes (Aleong et al., unpublished results). Functional neuroimaging results have also revealed weaker responses in EBA among females with an eating disorder compared with healthy women (Uher et al., 2005). In addition, males with low BMI did show hemispheric asymmetry in EBA response, indicating that males with low BMI show similar perceptual patterns of response to human bodies when compared with females of lower BMI.

In our study, individuals of relatively healthy BMI were shown images within the same range of their own BMI. Furthermore, presented body-images did not reflect subjects’ own bodies. Thus, one must question whether individuals with relatively high BMI (i.e., mean + 1 S.D.) failed to show any hemispheric asymmetry in EBA response merely because the presented body-images did not match the size and shape of their bodies. Or could this BMI-modulated suppression effect in the perception of human bodies be linked to differences in emotional/motivational investment regarding human bodies between obese and healthy individuals? In order to investigate these issues, future experiments must utilize larger-scale changes in body size and shape as well as image stimuli that match the observer’s BMI, and measure potential differences in the top-down attentional modulation of perceptual processes between obese and healthy groups.
In conclusion, our study offers direct evidence of the influence of cerebral hemisphere, sex, and BMI on the perception of human bodies. Women showed: (1) greater right EBA and FBA responses compared with left EBA and FBA, respectively and (2) greater right EBA response compared with males. Both EBA and FBA are sensitive to changes in body size with EBA showing greater sensitivity than FBA. Observer BMI modulated the response of EBA to human bodies. Application of our methodology among adolescents, patients diagnosed with an eating disorder, or obese individuals could prove helpful in identifying developmental trends and the neural underpinnings of the perception of human bodies.

4.8 Acknowledgements

Funding was provided by the Canadian Institutes for Health Research (R.A., T.P.) and the University of Nottingham (T.P.). The authors would like to acknowledge the contributions of Eileen Qian and John Totman in the data acquisition process as well as Denis Schluppeck for his input regarding the adaptation protocol. Correspondence regarding this article should be addressed to T. Paus, Brain and Body Centre, University of Nottingham, University Park, Nottingham NG7 2RD, United Kingdom (e-mail: tomas.paus@nottingham.ac.uk).
Chapter 5

Discussion and Conclusions
In this thesis, we have described a series of studies aimed at investigating the perception of human bodies at both behavioural and neural levels. In order to achieve this goal, we implemented a three-step investigation involving: (1) the design, creation, and characterization of novel experimental tools specific for the assessment of adolescent body-perception; (2) the behavioural evaluation of the accuracy of self body-size perception and detection sensitivity to changes in body size among healthy adolescents; and (3) the identification of neural substrates of the perception of body size and shape. Another important component of our investigation involved an examination of the influence of subject sex, age, and BMI on the perception of body size and shape, as evaluated at behavioural and neural levels. This systematic experimental approach addressed a number of methodological problems associated with previous studies.

The main behavioural findings of the thesis were as follows: (1) healthy adolescent males and females overestimated significantly their body size; (2) compared with males, adolescent females overestimated to a greater extent and showed greater detection sensitivity to changes in body size and shape; (3) body-size overestimation increased with age during adolescence; and (4) detection sensitivity increased with age and decreased with increasing observer BMI. In our effort to identify the neural substrates of the perception of body size and shape, we reported the following results obtained with fMRI during the presentation of body images: (1) healthy adult females showed greater right than left hemisphere responses in EBA and FBA; (2) greater right EBA response was observed in females compared with males; (3) observer BMI modulated EBA hemispheric asymmetry in both sexes; and (4) EBA and FBA were sensitive to subtle changes in body size and shape. We begin by discussing the development of the AdoBSD and AdoBMT in greater detail. We will then examine the implications of our behavioural
5.1 AdoBSD and AdoBMT Development

The AdoBSD and AdoBMT represent a clear evolution in the field of available techniques with which to assess the perception of body size and shape. We contend that the AdoBSD and AdoBMT account for a number of methodological limitations inherent to other techniques. The AdoBSD and AdoBMT: (1) are devoted specifically to the exploration of adolescent body-perception; (2) account for the natural covariations between body parts across multiple image views; (3) distort images in a standardized manner (e.g., standard deviation of the mean of the PC), thereby permitting the quantitative assessment of accuracy and detection sensitivity with regards to self body-perception; (4) allow for the perceptual assessment of body parts and whole bodies through the selection of PCs that morph specific body-parts and the presentation of whole body-images; and (5) can generate realistic, participant-specific, body-image stimuli.

To our knowledge, these tools represent the first mathematical model to simulate life-like changes in adolescent body-size and shape, as well as the first set of body-morphing tools specifically designed to morph images of adolescent bodies. Our use of a point distribution model and principal components analysis offers a unique opportunity to assess covariations in body size and shape, a feature that is lacking in many techniques. Consequently, the realism of the body-image stimuli was enhanced by these efforts. The AdoBMT may also be viewed as a compromise between the assessment of body parts versus the whole body. Other methods are typically directed towards one or the other. The nature of the principal components allows researchers to focus on particular body parts.
(e.g., PC4 focuses on the lower body including the hips, thighs, and calves) in the context of a whole-body image. Researchers may tailor their question with respect to individual body-parts of interest while maintaining whole-body realism. The AdoBSD and AdoBMT tools also allow for the generation of individualized body-image stimuli for each study participant since image acquisition, body-image tagging, and image morphing can be achieved in a real-time manner.

The applications of the products of Chapter 2 are two-fold. The *procedures and protocols* that were used to develop the AdoBSD and AdoBMT may be applied to any population. The image acquisition, body-tagging, and PCA modelling protocols may be used to develop databases and morphing tools for healthy adults, obese individuals, patients with anorexia nervosa, or individuals with severe body deformities (e.g., scoliosis). The protocols may also be used to generate ethnic-specific databases and tools. Some studies have examined potential differences between Caucasian, African-American, Asian, and Hispanic subjects with respect to body satisfaction (Cachelin, Rebeck, Chung, & Pelayo, 2002). These studies are often limited by their use of figural or silhouette-based scales that do not account for any ethnic differences between subjects. Thus, generation of an ethnic-specific database of morphed body-images using our body-morphing protocols could help address these scientific questions.

Given the standardized location of the body tag-points, one could even apply principal components across populations; for example, one could use disorder-specific principal components to morph the body images of healthy individuals to mimic the body morphology of the disorder among a healthy population and subsequently assess perceptual factors. Therefore, the developed methodology can, in and of itself, be a continuing contribution of this study.
The *adolescent*-specific database of body images may also be used to investigate other questions related to body perception. One could utilize the real and morphed body-images in a psychophysical experiment in which subjects explicitly indicate their ideal body-size as well as their perceived body-size, thereby producing an index of body satisfaction. The real and morphed body-images may also be used as visual stimuli for studies of the perception of a body’s sex, body-part naming, or emotional body processing (e.g., as neutral stimuli). At an extreme, the body images could be dissected for body parts in order to assess the role of EBA and FBA in the processing of body parts versus the whole body, respectively. This library of images, including both real and morphed bodies, offers *standardized* body-image stimuli to researchers, thereby eliminating or minimizing experimental confounders due to stance, subject clothing, or facial features.

One additional advantage of our methodology is the use of 2D anthropometric measures and an estimated BMI value to characterize the morphed body-image stimuli. These anthropometries-based classification methods mark a great improvement over many methods that use arbitrary descriptors (e.g., 10%) to describe linear stretching or shrinking of a body image. Such percentage descriptors, for example, would reveal little in terms of the precise dimensions of the morphed body-parts or the impact on the global size of the body. The 2D anthropometric system that we developed offers an opportunity to apply real-world dimensions to the 2D digital images in a fashion comparable to that of 3D anthropometric measurements. Thus, in the context of body size and shape perception, it would be possible to describe perceptual biases using body measurements, as opposed to theoretical constructs.

The fundamentals of this 2D system may also be used with other digital images.
(e.g., not from the AdoBSD) to describe body size and shape changes if the body tag-points are identified and a pixel per centimetre constant is established for a given image space. For example, digital images that have been acquired in the context of a medical assessment with no accompanying 3D anthropometric measures may be assessed using this 2D anthropometric system. As an extension, these 2D measures may be used to calculate an estimated BMI value for the same body. It should be noted, however, that the relationship between estimated body-volume and BMI that was described in Chapter 2 must be validated further with a larger population of subjects. Thus, an estimated BMI value based upon calculated total body-volume should be used with caution.

With the design and creation of the body-morphing tools and morphed images, we then completed a validation experiment that revealed a number of unexpected findings. Although the primary objective of the experiment was to validate the body-morphing parameters, interesting sex and BMI effects were observed with respect to the perceived “oddness” of the real undistorted images. Females rated low-BMI images as significantly less odd than high-BMI images, and significantly more so when compared with males. As mentioned previously, this is consistent with studies of body satisfaction in which females selected ideal body-sizes of thinner or smaller size when compared with their perceived body-size (Ambrosi-Randic, 2000; Brodie et al., 1994; Collins, 1991; Gardner et al., 1999b; Parkinson et al., 1998; Rolland et al., 1997; Sherman et al., 1995; Tiggemann et al., 1998; Williamson et al., 2001). Given these findings, one might speculate that this “oddness” approach may reflect an indirect experimental method of assessing body satisfaction. Although further validation is required, researchers might find it useful to employ this implicit strategy in addition to more explicit methods in studies of body satisfaction.
One potential limitation of our mathematical model was the use of both male and female bodies within a single PCA model. A combined male and female PCA model would likely limit the sex specificity of the body-image morphing. Separate male and female databases would obviously have been our preference; however, we were limited by subject recruitment and statistical power issues. Anecdotally, our difficulties in subject recruitment, which was often related to the wearing of the bodysuit by subjects, are quite interesting as they speak to the issues many adolescents may have about their body image.

Currently, the PCA model is based upon the source data derived from 160 adolescents with an available morphing range from -0.8 S.D. to +0.8 S.D. for a given PC. The validation experiment demonstrated that images morphed at and beyond the 0.5 S.D. level are likely too distorted for any practical use. One potential way to refine the images within the usable range of -0.4 to +0.4 S.D. might be to increase the size of the source population, thereby enhancing the PCA model and, potentially, revealing greater detail in body distortion with the model PCs.

Chapter 2 described two adolescent-specific assessment tools, the database and body-morphing tool, which may be used in future behavioural and neuroimaging experiments of body size and shape perception. The protocols and products of Chapter 2 may also hold wider significance for various clinical populations including patients with anorexia nervosa and obese individuals.

5.2 Assessment of Visual Body-Size and Shape Perception: Behaviour

In Chapter 2, we addressed a number of the methodological limitations associated
with many of the techniques used to generate distorted body-images. As a natural progression of our scientific objectives, our next step was to use these morphed body-images to perform behavioural and neuroimaging assessments of body size and shape perception among healthy adolescents and young adults, respectively. These two studies were conducted sequentially in order to identify sex, age, and BMI effects behaviourally and then identify potential neural substrates of those same effects using fMRI.

We introduced a number of methodological improvements into the behavioural protocol including the use of: (1) the adolescent-specific morphed body-images derived from the AdoBSD and AdoBMT; (2) the method of constant stimuli and random body-image presentation so as to minimize any anchor effects; (3) a cumulative sigmoidal function to discriminate between sensory (i.e., DL) and nonsensory (i.e., PSE) components of body perception; and (4) subject sex, age, and BMI as predictors in a multidimensional regression model of PSE and DL. In order to account for the anchor effects that have plagued previous studies, we used the method of constant stimuli in the presentation of the morphed body-images, whereby images of either larger or smaller size (relative to the subject’s real body-size) were presented in random order. The randomization prevented any systematic anchor bias inherent to ascending or descending series of body images. The resulting data were then used to calculate a cumulative sigmoidal function that allowed for the estimation of sensory and nonsensory components of body perception. The use of both the PSE and DL variables allowed us to distinguish two potentially independent components of body perception. Finally, few studies have examined all three factors of sex, age, and BMI within the same population of subjects having performed a single task. Thus, our study represented a unique opportunity to assess main effects as well as interactions between these factors.
The results of Chapter 3 clearly indicated that perceptual biases exist in both male and female adolescents. Females showed greater overestimation of self body-size but also greater detection sensitivity to changes in body size and shape when compared with males. These findings are consistent with existing data that indicate significant sex differences in various facets of body perception including the discrepancy between self-reported perceived and measured body-sizes (Brener et al., 2003; Davis et al., 1994; Strauss, 1999), overestimation of self body-size (Bergstrom et al., 2000), ideal body-size (Cohn et al., 1987; Collins, 1991; Kostanski et al., 1998; Parkinson et al., 1998), and body dissatisfaction (Eisenberg et al., 2006; Gardner et al., 1999b; Kostanski et al., 2004; Mendelson et al., 2001; Rosenblum et al., 1999). Our results provide additional support for the hypothesis that females and males perceive bodies in a different manner. Our work also stresses the importance of including both sexes in future studies of body perception.

The age effect observed in Chapter 3 is not entirely surprising given the dramatic changes in physical growth and appearance that occur during this period. During childhood and adolescence, there are a great number of changes that occur in both body size and composition. Prior to puberty, both sexes grow an average of 5-6 cm and 2.5 kg per year (Tanner, 1989). Puberty is characterized by a sudden acceleration in growth as well as sexual differentiation (Marshall et al., 1970; Marshall et al., 1969). Girls and boys grow at a peak height velocity of 9 cm and 10.3 cm per year, respectively (Tanner et al., 1966). With respect to weight gain, girls and boys reach peak growth values of 8.8 kg/year at age 12.9 years and 9.8 kg/year at age 14.3 years, respectively (Tanner et al., 1966). Sexual maturation is characterized by such stages as adrenarche and gonadarche with regulation by various hormones including testosterone, estradiol, and dehydroepiandrosterone sulfate (Rogol et al., 2002). Furthermore, body composition
changes dramatically during puberty; for example, sex differences emerge as pubertal females and males show increases and decreases in the percentage of body fat, respectively (Dai et al., 2002).

In light of these changes in body growth, we demonstrated that overestimation of body size increased with age during adolescence. Previous studies, however, have reported decreasing overestimation with age (Gardner et al., 1999a; Gardner et al., 1999b; Halmi et al., 1977), in direct contrast to our results. These conflicting findings, we believe, may be due to differences in the methodologies used and the study populations included in the various studies. For example, Halmi and colleagues utilized a unisex sample of females and the visual size-estimation technique with no use of body images (Halmi et al., 1977); thus, one must question whether visual perception of body size was truly assessed in this study. In the studies by Gardner and colleagues, subjects between the ages of 6 to 14 years were included (Gardner et al., 1999a; Gardner et al., 1999b). With this age range, perceptual biases may not have been identified since peak pubertal weight gain may not have been yet achieved among some of the study participants (Tanner et al., 1966).

Our finding of greater overestimation with increasing age is also more consistent with existing data detailing ideal body-size preferences and body dissatisfaction among adolescents. Both adolescent females and males have expressed a desire for a smaller, thinner, or leaner body-size relative to their perceived body-size (Brodie et al., 1994; Gardner et al., 1999b; Kostanski et al., 1998). Adolescent females, in particular, have reported increased body dissatisfaction with age (Gardner et al., 1999b; Kostanski et al., 2004; Rosenblum et al., 1999) and greater discrepancies between perceived and ideal body-sizes at advanced pubertal stages (Cohn et al., 1987). These findings are particularly
relevant in light of the physical changes described above, whereby adolescent females have demonstrated increased levels of body fat with age (Dai et al., 2002). Thus, increasing levels of body fat in concert with a desire for a thinner body-size would logically lead to increases in body dissatisfaction. With this discordance between actual and ideal body-sizes, one would anticipate that a perceptual bias, if present, would be in the direction of an overestimation of body size, as demonstrated in Chapter 3.

One should note, however, that increased perceptual bias (overestimation) was present despite an increase in detection sensitivity. Consequently, our results are indicative of a dissociation between these two components of body perception; overestimation of self body-size may not be the result of faulty sensory processing since detection sensitivity increases, but rather reflect a separate processing event.

Based upon these relationships between age and our dependent variables, we can conclude that adolescence is a key developmental period with regards to body perception. In this thesis, we used a cross-sectional study design; future work must investigate longitudinal changes within subject. Measuring within-subject performance in a prospective manner could also provide insight into the relationship between task performance and the development of dieting or eating-disorder behaviours.

In Chapter 3, a limited age range (10 to 17 years) of adolescents was tested. Future studies must address potential age-related differences in body perception among younger participants since females as young as 5-years-old have reported weight concerns and dissatisfaction with their bodies (Davison, Markey, & Birch, 2000; Davison et al., 2003). In Chapter 3, we reported significant overestimation across the age range of 10 to 17 years. Future studies must map developmental trajectories in response biases among younger subjects in order to establish at which age, if at all, children are capable of
estimating accurately their body size. Furthermore, an investigation of older subjects might prove essential in determining whether: (1) adolescents have reached a plateau in their degree of overestimation, (2) overestimation of body size continues to rise through young adulthood, and (3) elderly individuals show a different pattern of body perception.

An additional finding of Chapter 3 involved the decreased detection sensitivity found among individuals with larger BMI. This reduction in detection sensitivity indicates that larger subjects are less able to detect differences in body size and shape. This result must be interpreted with caution as the number of obese subjects in our sample was quite low. Nevertheless, the significant correlation does indicate a negative relationship between detection sensitivity and subject BMI, even within the context of the BMI variation present in subjects with relatively large, yet healthy, BMI values. This relationship is relative in nature; no absolute range in DL was established as indicative of clinical dysfunction, per se. This behavioural result is particularly relevant in light of the reports of increased obesity among adolescents and adults (Ogden et al., 2006; Tremblay et al., 2002). Although the literature remains divided as to whether body perception biases are typical of obese individuals (Gardner et al., 1989a; Gardner et al., 1988a; Gardner et al., 1989b), our results offer evidence in favour of decreased detection sensitivity to changes in body size and shape among individuals with larger BMI. Future research should investigate whether this reduction in detection sensitivity is present in clinically-diagnosed obese individuals, and whether it might play a role in the development and/or maintenance of obesity.

One must keep in mind, however, that the nature of the relationship between BMI and body perception remains unknown. For instance, is impaired perception of the body merely a by-product of having a larger body? Or does impaired perception of the body
contribute to the development of that larger body? One could, perhaps, begin to tease apart this relationship by assessing body-size perception before, during, and after losing or gaining significant amounts of weight within individuals. If, for example, individuals demonstrate significant changes in body perception following significant weight loss, then one might propose that physical body-size influences body perception. At the other extreme, future studies should also determine whether individuals with excessively low BMI (e.g., underweight or anorexic patients) demonstrate similar perceptual biases. With the advent of our morphing tools and behavioural protocol, one might be able to examine this question.

A key limitation of Chapter 3 is the high rate of subject exclusion in our analyses. The largest proportion of subjects was excluded based upon their failure to produce a sigmoidal relationship between the level of body distortion and subjects’ smaller/larger judgments. This may have been the result of: (1) the inversion of task instructions by the subjects, (2) an inadequate range of morphed body-image stimuli, and (3) conflicting changes in body parts within the morphed body-images. For subjects with flat curves, this indicates that subjects perceived all morphed images as either larger or smaller than their real body-size. This could mean that the number of morphed stimuli or the range of morphing used was insufficient to capture the subject’s PSE.

We also examined the visual properties of the morphed body-image stimuli. Upon closer examination, it was noted that while the majority of body parts decreased in size with negative changes in S.D. of the mean of PC4, this was not the case for the length of the legs. This discrepancy between leg length and the rest of the body was inherent to the principal components model used to characterize the natural covariations in body size and shape (Aleong et al., 2007). Therefore, subjects could have generated an inverted curve if
they focused exclusively on changes in leg length across all morphed conditions. Finally, if subjects failed to remain consistent in their choice of body-part criterion or if they failed to use a global impression of the presented body-image, an inconsistent curve could have been the result, with no obvious curve trend in the data.

From the results of Chapter 3, we can conclude that subject sex, age, and BMI modulate perception of body size and shape, as defined by the accuracy of self body-size estimation and detection sensitivity to changes in body size and shape. Our next step was to identify the neural substrates of these effects. We predicted a priori that: (1) the body-selective brain regions, EBA and FBA, would be involved in the perception of body size and shape and (2) EBA and FBA responses would be modulated by subject sex and BMI, indicating that these functional regions are the neural substrates of the behavioural effects described in Chapter 3.

5.3 Assessment of Visual Body-Size and Shape Perception: Brain Function

In the wider realm of object recognition, the human LOC has been implicated in the selective perception of objects when compared with texture patterns or random visual noise (Malach et al., 1995). Researchers have extended this finding by assessing whether object-selective brain regions, including the LOC, respond to objects irrespective of such characteristics as object size. Previous studies have explored size sensitivity in object-specific brain regions including monkey inferotemporal complex (Desimone et al., 1984; Ito et al., 1995; Logothetis et al., 1995; Sato et al., 1980; Schwartz et al., 1983) and human FFA and LOC (Ewbank et al., 2005; Grill-Spector et al., 1999; Malach et al., 1995; Malach et al., 1998; Sawamura et al., 2005; Vuilleumier et al., 2002).
Electrophysiological recordings of neuronal activity in the monkey IT cortex have revealed some object-selective responses which are generally invariant to changes in object size (Desimone et al., 1984; Ito et al., 1995; Logothetis et al., 1995; Schwartz et al., 1983). These results are corroborated by fMRI studies that have shown minimal or no effect of changes in object size on response levels in the LOC (Malach et al., 1995) or the degree of adaptation in the LOC and ventral temporal areas (Ewbank et al., 2005; Grill-Spector et al., 1999; Malach et al., 1998; Vuilleumier et al., 2002).

A closer examination of the adaptation effect in monkey IT cortex and human LOC has revealed functional subdivisions that show differential adaptation recovery in response to changes in face size (Grill-Spector et al., 1999). A caudal-dorsal region located lateral and posterior to area MT and extending into the posterior inferior temporal sulcus showed substantial recovery from adaptation with changes in face size; in contrast, the anterior-ventral region located within the fusiform gyrus and extending into the occipitotemporal sulcus displayed sustained adaptation in response to size changes (Grill-Spector et al., 1999). Similarly, size invariance was incomplete in monkey IT and human LOC, with greater size invariance in the anterior LOC compared with the posterior LOC (Sawamura et al., 2005).

Thus, human faces may represent a special biological category for which the encoding of face dimensions may be necessary. In an effort to explore this issue further, faces and cars were utilized as two distinct object categories in an fMR-adaptation experiment comparing the neural response to rotation and translation of these objects (Grill-Spector et al., 1999). The results revealed similar adaptation effects and sensitivity to rotation and translation for both faces and cars (Grill-Spector et al., 1999). It should be noted, however, that a direct comparison of size invariance between these two categories

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was not carried out. Therefore, the existing literature suggests that the human brain is sensitive to face size.

These face-related findings lend naturally to the question of whether human bodies also represent a biological category of object that benefits from specialized neural processing of size. Already, we have described that the perception of human bodies may be considered distinct from that of other objects, as evidenced by studies describing: (1) the body-inversion effect (Reed et al., 2003; Reed et al., 2006), (2) significant capture of attention by human bodies (Downing et al., 2004), and (3) the identification and characterization of body-selective brain regions such as EBA and FBA (Downing et al., 2001; Peelen et al., 2005a; Schwarzlose et al., 2005). There has been little exploration of the precise body features to which EBA and FBA are sensitive. For example, are EBA and FBA sensitive to changes in body size and shape, analogous to the LOC sensitivity to face size that has already been described (Grill-Spector et al., 1999)? If so, do EBA and FBA responses to human bodies depend on an individual’s sex, age, and BMI? In other words, could EBA and FBA be the neural substrates of the behavioural effects outlined in Chapter 3?

In Chapter 4, we described a series of findings that we believe are consistent with our *a priori* hypotheses. We showed that EBA and FBA are sensitive to subtle changes in body size and shape, as defined by a significant recovery in BOLD signal from a repetition-induced adaptation effect, thereby indicating that both EBA and FBA treated body images of varying size as distinct and novel body-stimuli. We believe that the adaptation paradigm used in Chapter 4 is an appropriate method to assess the neural correlates of detection sensitivity to changes in body size and shape, which we had investigated previously using a DL measure. Therefore, we offer the findings of Chapter
4 as evidence that EBA and FBA are the neural substrates for the processing of body size and shape.

The precise mechanism of body size and shape perception remains unclear; yet, there is some evidence suggesting that there may be a division of processing labour between EBA and FBA. As we demonstrated in our study, EBA showed greater sensitivity to changes in body size compared with FBA. This is consistent with previous fMRI findings that also reported a more gradual increase in EBA response to an increasing number of visible body-parts and a step-like increase in FBA response with the appearance of larger portions of the body (Taylor et al., 2007). Along these lines, one might speculate that EBA processes changes in body-part size, whereas FBA processes larger-scale body-size changes.

What is the functional importance of body size and shape processing? As previously described, face-size sensitivity has been shown in LOC (Grill-Spector et al., 1999) and, in our studies, body-size sensitivity in EBA and FBA. A strong argument may be made that faces and bodies are special categories of objects for which size invariance is undesirable. From an evolutionary perspective, size perception of bodies may be necessary in order to evaluate an individual’s sex, identity, and potential threat as well as permit proper orientation and positioning of one’s own body relative to another. Future experiments should be designed to compare both faces and bodies with nonbiological objects (i.e., cars) with respect to size invariance in order to verify the sensitivity of the human brain to body and face size, relative to other nonessential objects.

An important caveat must be considered regarding our findings. All body-image stimuli used in Chapter 4 were unfamiliar and presented using an allocentric viewpoint. Thus, our conclusions regarding the role of EBA and FBA in processing body size and
shape should be, at this point, applied to the bodies of others only. Nevertheless, our results may provide some insight into EBA’s proposed contribution to an individual’s self-other distinction or sense of agency. Previous studies have hypothesized that EBA may aide in the: (1) processing of self as demonstrated by a significant EBA response during the planning or execution of self-generated movements (Astafiev, Stanley, Shulman, & Corbetta, 2004; Jeannerod, 2004); (2) processing of others as evidenced by greater right EBA response to allocentric relative to egocentric body-images (Chan et al., 2004; Saxe et al., 2006); or (3) detection of incongruencies between internal body or action signals and reafferent visual signals (David et al., 2007; David et al., 2008). In light of our findings, we speculate that body size and shape perception via EBA and FBA processing may provide valuable discriminatory information with regards to the identity of a body part or whole body (e.g., self versus other).

Future studies must examine the role of EBA and FBA in the processing of self body-size and shape. As we only used other individuals’ bodies, one must question whether EBA and FBA may also be involved in the processing of one’s own body image. We predict that EBA would also respond to changes in self body-size and shape since a significant EBA response has been observed upon presentation of both egocentric self and other body-images (Chan et al., 2004). The question remains as to whether EBA and FBA would show different adaptation response profiles with respect to self body-images. Replication of the adaptation experiment using subject-specific body-images could help answer this question.

In Chapter 4, we also demonstrated that EBA and FBA responses may be modulated by subject sex and BMI. In both block-design and adaptation experiments, females demonstrated significantly greater right versus left hemisphere responses for both
EBA and FBA. No hemispheric differences were observed among males. Females also showed greater right EBA responses, compared with males, in the block-design experiment. These significant sex effects dovetail nicely with the behavioural results described in Chapter 3, which described greater detection sensitivity to body-size changes among females compared with males. Thus, we argue that the neural substrates of the behavioural sex effects outlined in Chapter 3 include EBA and FBA.

The hemispheric asymmetry demonstrated exclusively by female participants may be indicative of finer discriminatory processing of body configuration among females. For example, in Chapter 4 we described studies that have shown a preferential right EBA response for allocentric body-images (versus egocentric body-images) and a greater right EBA sensitivity to body parts when compared with left EBA (Chan et al., 2004; Saxe et al., 2006; Taylor et al., 2007). Therefore, one might speculate that female-specific right EBA dominance may signify greater sensitivity in the processing of body parts when compared with males.

In addition, subject BMI modulated the EBA hemispheric effect in the block-design and adaptation experiments, as individuals with larger BMI failed to demonstrate differences between left and right EBA responses. This effect of observer BMI is consistent with our behavioural results, whereby individuals with larger BMI showed reduced detection sensitivity as measured by the DL variable. Given that we have demonstrated significant effects of subject BMI on the perception of body size and shape, as defined by both behavioural and neuroimaging measures, we propose that the depth of processing of human bodies is lower in subjects with high BMI. We hypothesize further that clinical conditions related to subject BMI, including obesity and eating disorders, may involve significant differences in EBA response. Evidence in support of this
hypothesis has already been provided by an fMRI study that reported weaker EBA responses in patients with an eating disorder compared with healthy controls (Uher et al., 2005). Although our study did not include obese participants, we did show that individuals with larger BMI exhibit "weaker" EBA responses compared with individuals with relatively healthier BMI. Based upon our results, we predict that clinically obese individuals would also show a differential EBA response profile (i.e., reduced EBA hemispheric differences). Given the fMRI findings in patients with an eating disorder (Uher et al. 2005) and our observations, there appears to be an inverted-U relationship between EBA response and BMI, whereby individuals with extreme BMI (e.g., patients with anorexia nervosa and obese individuals) show weaker EBA responses. We propose that individuals whose BMI fall outside a healthy range process bodies less extensively, a fact that is manifested as a weaker EBA response.

All of our results must be interpreted in the context of existing knowledge about the neural representation of the human body. A central representation of one’s own body size and shape is the product of an integration of various sources of information. As demonstrated by the phenomena of phantom limb awareness and body illusions, processing of sensory inputs by the primary somatosensory cortex may play a vital role in determining body position as well as body size and shape (Ehrsson et al., 2005; Grüsser et al., 2001; Lackner, 1988; Ramachandran et al., 1998). These somatosensory inputs alone, however, are not sufficient to establish body size and shape. Visual inputs are obviously another integral component which must be considered. For example, when inducing a body illusion using anaesthetic block, changes in body size were perceived as an illusion only after subjects saw or grasped the anaesthetized limbs (Paqueron et al., 2003). The reconciliation of sensory and visual inputs resulted in a modified, but ultimately, unified
We conclude that our neuroimaging data contribute to this integrative multimodal model of body size and shape perception. As previously suggested, EBA and FBA are likely responsible for processing visual information about body form, whether it be of body parts or of the whole body (Taylor et al., 2007; Urgesi et al., 2007a). We offer evidence that EBA and FBA also contribute to the visual determination of body size and shape. This information may then be integrated into a central representation of body size and shape, taking into account other sensory information derived from, for example, tactile and proprioceptive inputs. As part of the ventral visual stream, EBA and FBA may play a role in the determination of body size and shape not only for static body-images, as seen in Chapter 4, but also of bodies in motion, as predicted by the model proposed by Giese and Poggio (Giese et al., 2003).

The results of the fMRI study raise a number of interesting research questions regarding the role of EBA and FBA in the perception of human body-size and shape. In this dissertation, we demonstrated the ability of EBA and FBA to respond to changes in body size and shape. These changes, however, were fairly complex in nature, encompassing multiple body-parts in the context of a whole body-image presentation. Future studies must investigate whether EBA and/or FBA play specialized roles in processing size changes at a body-part versus whole-body level, respectively. In order to answer this question, one should present isolated changes in body-part size compared with changes in whole-body size as shown in Chapter 4. Three main areas of future research should also include: (1) characterization of EBA and FBA responses to other manipulations of human bodies (e.g., identity, viewpoint, rotation); (2) examination of the influence of other modulatory factors such as emotional body expression on EBA and
FBA responses; and (3) exploration of EBA and FBA function in different populations of study participants.

We established that sex and BMI modulate both behavioural and neuroimaging measures of body perception. Although we did demonstrate a significant developmental effect in Chapter 3, we did not address this factor in the fMRI study. Future investigations must determine if there are significant age effects on EBA and FBA function, as predicted by our behavioural findings. In order to address this question, the protocol in Chapter 4 should be replicated using an adolescent population. In addition, given the significant effects of both sex and BMI, future studies should investigate the potential influence of gonadal hormones and other satiety-related neuropeptides that may affect eating behaviour, body composition and consequently, body perception. These compounds include estradiol, testosterone, leptin, orexin, and ghrelin.

Throughout all three studies, we focused upon healthy individuals, both adolescents and young adults. Future investigations should focus on clinical populations including obese individuals, both adolescent and adult. In a behavioural experiment, a larger group of obese participants would enhance the statistical power of the study, thereby giving us the opportunity to comment on the potential effects of subject BMI on accuracy of estimation and detection sensitivity with greater certainty. With respect to a neuroimaging study, our questions would be two-fold. Would obese individuals show the same adaptation effects if viewing obese body-images? In other words, does an observer's BMI interact with the BMI of the image to affect the perception of the body image? The validation experiment from our first study does offer some indirect evidence that the BMI of an image may play some role in the perception of the body, as females rated low-BMI images as significantly less odd than high-BMI images.
Obviously, another clinical application would be to implement the adaptation protocol among patients with anorexia and bulimia nervosa. Although the behavioural evidence suggests that there does exist a perceptual bias in body-size estimation among patients with an eating disorder (Garner et al., 1976; Gila et al., 2005; Slade et al., 1973; Whitehouse et al., 1988), the protocol of Chapter 4 offers a unique opportunity to assess whether patients with anorexia and bulimia nervosa show an atypical neural sensitivity to changes in body size and shape, as assessed by the fMR-adaptation effect.

5.4 Conclusions

In conclusion, this dissertation has contributed new knowledge to the field of visual body-perception. We have designed, created, and characterized a novel adolescent-specific body-morphing tool and library of digital body-image stimuli that can be used in future studies of body perception. Furthermore, we have demonstrated that subject sex, age, and BMI modulate an individual's accuracy of self body-size estimation and sensitivity to changes in body size and shape. Female adolescents showed greater overestimation of body size and greater sensitivity to changes in body size compared with male adolescents. Body-size overestimation increased with age. Detection sensitivity increased with age and decreased with increasing observer BMI. Finally, we identified human EBA and FBA as the neural substrates of human body-size and shape perception as well as the site of action for the modulatory influence of subject sex and BMI.

Based upon our findings, we can make five main conclusions: (1) males and females process human body-images in a different manner, as demonstrated by both behavioural and neuroimaging measures; (2) self body-perception is modulated by age,
particularly during adolescence; (3) individuals with a higher BMI show differences in body perception compared with individuals with lower BMI; (4) EBA and FBA contribute to the detection of changes in body size and shape; and (5) EBA and FBA are likely the neural substrates of the aforementioned modulatory influence of sex and BMI. Our findings offer insight into the visual processes underlying healthy perception of body size and shape while also holding important implications for various clinical conditions including obesity and eating disorders.
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Appendix A

Abbreviation List
2D = two-dimensional
3D = three-dimensional
AdoBSD = Adolescent Body-Shape Database
AdoBSD MEQ = Adolescent Body-Shape Database matching-error quotient
AdoBMT = Adolescent Body-Morphing Tool
AN = anorexia nervosa
ANOVA = analysis of variance
APE = adaptive probit estimation
BESAA = Body-Esteem Scale for Adolescents and Adults
BIA = Body Image Assessment
BM = biological motion
BMI = body mass index
BN = bulimia nervosa
BOLD = blood oxygenated-level dependent
BPI = body perception index
BRS = Body Rating Scale
CAD = Canadian dollar
CBCL = Child Behaviour Checklist
CDC = Centers for Disease Control
ChEAT = Children’s Eating Attitudes Test
CI = confidence interval
DISSI = Quick Diagnostic Interview Schedule III-R
DL = difference limen
DSM = Diagnostic and Statistics Manual of Mental Disorder
EAT-26 = Eating Attitudes Test
EBA = extrastriate body area
EDI-2 = Eating Disorders Inventory
EEG = electroencephalography
ERP = evoked response potential
FBA = fusiform body area
FFA = fusiform face area
tfMRI = functional magnetic resonance imaging
FRS = Figure Rating Scale
ISI = interstimulus interval
IT = inferior temporal cortex
ITI = intertrial interval
LOC = lateral occipital cortex
MRI = magnetic resonance imaging
OBE = out-of-body experience
OFA = occipital face area
PC = principal component
PCA = principal components analysis
PDM = point distribution model
PEMCS = prenatal exposure to maternal cigarette smoking
PPA = parahippocampal place area
PSE = point-of-subject equality
rTMS = repetitive transcranial magnetic stimulation
RT = reaction time
SD = standard deviation
SE = standard error
SEM = standard error of the mean
SPL = superior parietal lobe
STS = superior temporal lobe
TPJ = temporo-parietal junction
vPMc = ventral premotor cortex
Appendix B

Ethics Certificates

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Ethics Certificates

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Appendix D

Ethics Certificates

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Copyright Waiver

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Appendix F

Article Reprint

Chapter 2
Assessment of adolescent body perception: Development and characterization of a novel tool for morphing images of adolescent bodies

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We developed a computer-based method of distorting adolescent body images, which incorporates the covariation between body parts found during growth and sexual maturation. An Adolescent Body-Shape Database (AdoBSD) and Adolescent Body Morphing Tool (AdoBMT) are described; the AdoBSD comprises real (n = 320) and morphed (n ~ 41,000) images (front and side view) of 160 adolescents (9-17 years). We used a point distribution model, based upon principal components analysis, to characterize the covariation between pre-defined body tag-points manually positioned on the body images and to morph the body images in a realistic manner. Eight principal components (PCs) were found to characterize 96.3% of the covariation between body tag-points. Application of the PCs to the body images resulted in the manipulation of body parts including shoulder width, waist, hip, belly, thigh and calf sizes. The AdoBMT and AdoBSD may be used to investigate changes in body perception during adolescence, and the role of body perception in adolescent obesity and eating disorders. The AdoBSD is available to the research community (www.brainbody.nottingham.ac.uk).

Body image has been described as "the picture we have in our minds of the size, shape and form of our bodies; and to our feelings concerning the size, shape and form of our bodies, and its constituent body parts" (p. 20) (Slade, 1988). This definition encompasses two key components that have been identified in the assessment of body image: (1) a perceptual component of body size and shape and (2) an emotional or attitudinal component as an index of body satisfaction (Skrzypek, Wehmeier, & Remschmidt, 2001; Slade, 1988).

It has become increasingly important to examine this issue during adolescence as numerous studies have demonstrated a clear trend of increased childhood and adolescent obesity (Chinn & Rona, 2001; Ogden, Flegal, Carroll, & Johnson, 2002; Strauss & Pollack, 2001; Thompson, Baxter-Jones, Mirwald, & Bailey, 2002; Tremblay, Katzmarzyk, & Willms, 2002), as well as a relationship between adolescence and eating disorders (Hsu, 1990; Lucas, Beard, O'Fallon, & Kurland, 1991). A study investigating the changes, between 1981 and 1996, in the body mass index (BMI) of Canadian children and adolescents (7-13 years of age) reported a 22% and 14% increase in the number of overweight boys and girls, respectively (Tremblay et al., 2002). With respect to body perception, some reports have indicated that obese individuals show no difference in body perception when compared with controls (Gardner, Martinez, & Espinoza, 1987; Gardner, Morrell, Watson, & Sandovol, 1989; Probst et al., 1995); in contrast, other studies have reported that obese individuals overestimate the size of their body (Gardner, Gallegos, Martinez, & Espinoza, 1989; Gardner, Martinez, Espinoza, & Gallegos, 1988; Rhodes & O'Neil, 1997). These conflicting results are likely due to methodological variations. Nevertheless, these changes in the size and shape of child and adolescent bodies stress the importance of examining how such physical transformations interact with the image of the body in the adolescent's mind.

Clinically, perception of one's own body may be of particular importance in anorexia and bulimia nervosa, two eating disorders that often begin during adolescence (Hsu, 1990). Perhaps not surprisingly, a larger perceived size and smaller ideal body size may predict higher eating disorder scores in adolescence (Gardner, Stark, Friedman, & Jackson, 2000). Thus, a fundamental understanding of adolescent body perception may offer insight into the development of anorexia and bulimia nervosa.

Over the past four decades, numerous techniques have been used to assess body image in adolescents and adults. These techniques may be divided into three major categories: (1) tools that do not utilize any visual presentation of
a body image, such as questionnaires, the image-marking technique and visual-size estimation technique (Askevold, 1975; Maloney, McGuire, & Daniels, 1988; Mendelson, Mendelson, & White, 2001; Reitem & Cleveland, 1964; Slade & Russell, 1973), (2) tools that utilize a mock silhouette or body image to represent the subject, such as the Figure Rating Scale and Collins’ pictorial figures (Collins, 1991; Stunkard, Sorenson, & Schulzing, 1983) and (3) tools that utilize distortion of real body images, such as distorting mirrors, video-based distortions and computer morphing software (Allebeck, Hallberg, & Esmark, 1976; Benson, Emery, Cohen-Tovee, & Tovee, 1999; Probst, Van Coppenolle, Vandereycken, & Goris, 1992; Traub & Orbach, 1964). Computer-based morphing tools are the latest addition; these techniques simulate life-like changes in body-shape and size (Benson et al., 1999; Gardiner & Boice, 2004; Gruber, Pope, Borowiecki, & Cohane, 1999; Harari, Furst, Kiyat, Caspi, & Davidson, 2001; R. Sands, Maschett, & Armutas, 2004; Shibata, 2002; SMEETS, 1999; Stewart, Williamson, SMEETS, & Greenway, 2001). Even the most recent software tools, however, may not be ideal for the study of adolescent body perception. To date, some tools use reference data from adult bodies (Benson et al., 1999); thus, the defined variation in adult body-shape would fail to account for the degree of variations in adolescent bodies due to growth and sexual maturation. Another potential limitation of these various computer-graphic techniques involves the morphing of individual body parts independently of each other with subsequent smoothing of adjacent areas. This type of morphing fails to take into account the natural covariation of individual body parts such as a correlated hip and thigh enlargement.

In order to address some of these methodological issues, we wished to use a modeling approach for body-shape morphing that was data-driven and not constrained by a priori information. Principal components analysis (PCA) of a large number of landmarks from a set of training images was thus selected to model body size and shape variations among healthy adolescents. PCA permits the integration of data regarding all body parts simultaneously into a single model with multiple image views. This characterization of variation across all body parts provides the opportunity to morph body images in a naturalistic, global manner.

Here, we describe the development of a computer-morphing tool specifically designed for the testing of adolescent body perception. In order to define natural variations in body-shape in an adolescent population, a novel Adolescent Body-Shape Database (AdoBSD) was created, consisting of front and side images of adolescents; age, sex, height and weight data for each individual were also included. PCA of manually placed landmarks on these images was used to identify groupwise covariations between body parts across the two image views. The established principal components model was subsequently used to create a novel Adolescent Body Morphing Tool (AdoBMT). This tool was used to distort real images quantitatively according to natural covariations in adolescent body-shape, as defined by the individual principal components (PCs). This step produced morphed but realistic body images of varying size that may be used in future tasks testing adolescent body perception and satisfaction.

In addition, we developed a two-dimensional (2-D) anthropometric system to characterize the body dimensions of both real images (i.e., source population) and morphed images. This allowed us to characterize the induced variations in body-shape using parameters similar to 3-D anthropometrics, such as circumferences and BMI values. We then completed a behavioral study examining the perceptual realism of the morphed body images. In an effort to identify appropriate morphing parameters for future experiments, we report distinct distortion effects as well as response profiles for specific PCs. The current paper is organized into three sections detailing: (1) the Adolescent Body-Shape Database (AdoBSD), (2) the Adolescent Body Morphing Tool (AdoBMT), and (3) a behavioral validation experiment for the AdoBSD and AdoBMT.

**ADOLESCENT BODY-SHAPE DATABASE (AdoBSD)**

**Method**

**Subjects.** Male and female subjects ranging in age from 9 to 17 years were recruited from the Montreal community through local advertising (see Results for the description of the sample). The Research Ethics Board of the Montreal Neurological Institute and Hospital approved all experimental protocols. Informed parental/guardian consent and subject assent were obtained for all participants.

**Procedure**

**Subject preparation.** All subjects were asked to change into a white cotton undershirt, red Lycra bodysuit and red fleece ski mask; various sizes of the Lycra bodysuit were available. The undershirt was worn underneath the bodysuit while the ski mask was utilized to protect the subject's identity. The Lycra bodysuits were purchased from a local dance-equipment supplier while the cotton undershirts and ski masks were purchased from a local general merchandise store.

The date of birth and sex were recorded, and height and weight measurements obtained at the beginning of the session. The child was positioned within the standard background and two digital images were acquired. Movie certificates were given to all subjects as compensation for their time and inconvenience.

**Image acquisition.** To minimize positional variations in image acquisition, a standard layout was used for all subjects. A single navy-blue piece of fleece material (203 X 287 cm) was used as a background. The material was pulled taut within a rigid wooden frame with a portion of the material arranged on the floor. To indicate a consistent standing position for each subject, pieces of gray tape were placed on the wall and floor to delineate arm and foot positions, respectively (Figure 1). Images were acquired in a room (7.5 X 3.9 m) that had unimpeded fluorescent lighting and afforded the participant privacy.

Images were acquired from both front and side views. These views were selected as the most familiar to potential subjects as they reflect common mirror perspectives. For that reason, other views such as a back silhouette image were not included. For the front view, subjects were instructed to stand facing the camera with their feet parallel to each other, 38 cm apart, within the tape borders placed on the floor. The experimenter positioned the arms of each subject between the tape borders on the wall. The distance between the hands along the...
ADOLESCENT BODY-SHAPE DATABASE AND BODY MORPHING TOOL

A total of 160 adolescents (73 males, 87 females) were recruited for the AdoBSD. Frequency distributions for subject age and BMI are detailed in Figures 2A and 2B, respectively. The mean ages for male and female subjects were 12.78 years (SEM = 0.25) and 12.95 years (SEM = 0.25), respectively. The mean BMI values for male and female subjects were 19.91 kg/m² (SEM = 0.40) and 19.64 kg/m² (SEM = 0.35), respectively. Independent samples t-tests revealed no significant differences between males and females for age or BMI (p > .05).

Method

Linear registration. In order to perform comparative analysis of body-shapes, images from the AdoBSD had to be first positioned into a single spatial frame of reference. Reference tags were manually positioned on both front and side images using the interactive volume display and point-tagging program, Register (David MacDonald: www.bic.mni.mcgill.ca/software/register/register.html). Six tags in the front view and four tags in the side view were placed at predetermined corners of the tape borders (Figure 1). A linear registration procedure was completed using MATLAB 7.1 (MathWorks, Natick, MA). Registration was used to match each image tag-point on the background tape markers with those from a selected reference using a transformation with 7 degrees of freedom (i.e., 3 rotations, 3 translations, 1 scale). The objective of this linear registration was to remove the global effects of pose, perspective and variation in the subjects' position relative to the background.

Body tagging and interrater reliability. Following linear registration, two raters manually positioned 36 (front view) and 18 (side view) body tag-points at defined body landmarks (Figure 3). These body tag-points were identified according to adapted anthropometric definitions (Lohman, Roche, & Martorell, 1991). The origin of our coordinate system was located at the bottom left corner of the images. After tagging, the background of each image was set to black in order to remove all visual cues in the morphed images. Two raters completed the body-tagging process twice on the same 20 subjects in order to assess interrater reliability.
Body Mass Index (kg/m$^3$) \(D(n=87)\)

Figure 2. Adolescent body-shape database. Age (A) and body mass index (B) frequency distributions for males and females are presented.

Point distribution model. All modeling and image morphing was completed with MATLAB 7.1. In order to capture shape variations across individuals, a point distribution model (PDM) was used (Cootes, Taylor, Cooper, & Graham, 1995). Point distribution models have been used extensively in the medical imaging literature; they rely on the assumption that global object-change variations can be reliably estimated by modeling the spatial distribution of series of appropriately placed and corresponding landmarks positioned on object representations.

Our model was built using data from both male and female subjects across all ages. Proper sampling of the object boundary is an important element of the model and thus, we identified 36 tag-points in the front view and 18 tag-points in the side view, corresponding to the edges of body areas of morphological interest. The PDM was created by completing PCA of the entire data set of body tag-points (i.e., 160 subjects \(x\) [36 front and 18 side tag-points]) as represented by continuous vectors \(v\) of \((x, y)\) coordinates (Cootes et al., 1995), concatenating front and side views together. With PCA, one can express each instance of \(v\) as

\[ v = \bar{v} + P_B v_B \]

where \(\bar{v}\) is the mean normalized shape vector, \(P\) is a set of orthogonal modes of variation, and \(B\) is a set of coordinate parameters. This representation spans a multidimensional ellipsoid including all shape instances from the data set, as well as other possible shape instances that may not be present in the database.

In order to identify the contribution of each principle direction in the description of the total variance of the system, the ratio of relative importance of the eigenvalue \(\lambda_i\) associated with the eigenvector or principal component \(k\) is used:

\[ r_k = \frac{\lambda_k}{\sum_{j=1}^{p} \lambda_j} \]

where the fraction \(r_k\) is the relative importance for eigenvalue \(\lambda_k\) over the sum of all \(\lambda_i\), since \(p\) is the total number of eigenvectors.

Image morphing. Morphed body images were created by adding multiples (up to \(\pm 0.8\) SD in 0.1-SD steps) of the standard deviation (SD) of the mean of each PC to the \((x, y)\) coordinates of the body tag-points of the original body images. These transformed points were then used as anchors to derive a smooth 2-D thin-plate spline transformation (Bookstein, 1989), thereby morphing the original images to produce a body of greater or smaller size. The thin-plate spline is the 2-D analog of the cubic spline in one dimension. We used it here to derive the transformation field interpolating between pre- and postwarped points.

The morphed images were then linearly transformed again (i.e., translation and rotation but no scaling) to the average shape \(\bar{v}\), en-
ensuring that all images were properly centered when presented on the computer screen.

PCA characterizes covariations between body tag-points; therefore, the morphing process resulted in a dynamic procedure whereby body parts that were found to covary among database subjects were also morphed simultaneously as dictated by the PCs. Moreover, PCA calculated covariations between tag-points in both front and side body images, thereby delineating the concurrent changes in body-shape and size across the two perspectives in a global manner.

**2-D anthropometric measurements.** Other body morphing techniques often quantify the degree of body distortion using a global percentage change value without any direct link to physiological body measurements (Harari et al., 2001; R. Sands et al., 2004). In order to quantify (1) the real body dimensions of the 160 AdoBSD subjects and (2) the anthropometric-like changes induced by application of each PC to the body images, we first defined a series of 2-D anthropometric measures within our images that best mimic 3-D anthropometric measures. The use of a 2-D anthropometric system allows for the qualitative and quantitative assessment of output stimuli, as well as a biological characterization of morphing, thereby giving researchers the capacity to select morphing parameters based on body morphology.

These 2-D measures were calculated as caliper distances between certain body tag-points as graphically represented in Figure 4. Anthropometric distances were calculated as the difference between the respective x and y coordinates for each body tag-point involved, converted into metric units using a pixel/cm constant. Distances were calculated for both real and morphed body images.

**Characterization of body morphing using body mass index (BMI).** Although the 2-D anthropometric system allows for the characterization of quantitative changes in body parts with changing levels of imposed distortion, the system fails to provide global information about potential changes in BMI. The use of BMI in characterizing changes imposed by the AdoBMT would permit the use of biologically relevant terminology and facilitate comparison of the morphed body images to real-life measurements of potential volunteers.

Not knowing the weight of the distorted bodies represents an obvious difficulty for calculating the BMI of morphed images. We estimated virtual BMI values from an estimate of body-volume and predicted the virtual BMI values using the observed linear relationship between the body-volume and BMI of the real 160 subjects (see below). The body-volume of an individual was estimated by segmenting the body into three cylindrical components: (1) torso, (2) right leg and (3) left leg. The radius and height of each of the three body cylinders were calculated using the distances between established body tag-points. Individual volumes were determined for each of the cylinders and then summed for a grand volume total.

### Results

#### Body tagging and interrater reliability.** Two raters (R. A. and S. D.) tagged a total of 40 images, including the front and side views of 20 subjects. In the front view, some tag-points were subject to wide positional variation across participants. For this reason, four tag-points were removed from the PCA model (i.e., left/right knee and left/right hand). The knee tag-points were excluded as the raters could not consistently identify the middle of the kneecap in each image. The hand tag-points were removed due to the variable nature of the arm position for individual subjects. In the side view, a total of three body tag-points were removed from the analysis, including the finger and two distal-thigh points. The finger point was excluded due to the great variability in arm position across subjects. The distal-thigh points were removed due to the inability of the raters to identify consistently those points in the images across subjects. Thus, a total of 47 tag-points were included in the final PC analysis.

In order to measure interrater reliability of the positioning of all 54 body tag-points, two dependent variables were assessed separately: (1) mean distance between the raters' points as an indicator of tagging error and (2) correlation between anthropometric measures derived from each rater's tag-points. In the first method, the mean

---

**Figure 3.** Standardized body tag-points. Manual body tag-points (i.e., black circles) were placed on each subject body, in accordance with adapted anthropometric definitions.
Euclidean distance between the points of two raters was calculated for each body tag-point. In order to identify body tag-points where the tagging error was significantly different from the minimum error of zero, multisample 95% confidence intervals were used with the minimum tagging-error value arbitrarily set as a population mean of zero. Our analysis revealed that no body tag-point fulfilled the statistical criteria for a mean error distance of zero ($p > .05$, Tables 1A and 1B).

In practical terms, however, the confidence intervals for only 7 out of 54 body tag-points showed a maximum interval value greater than 20 pixels. These seven body tag-points include the knee, breast and shoulder in the front view and the upper back and distal thigh in the side view.
The covariation between body tag-points with the first point was calculated so as to provide a visual representation of the average body for both males and females in (r = .492, p < .05) (Table 2). There were exceptionally strong positive correlations (r > .90) between an anthropometric measure and the results indicate that there may not have been identified in the front perspective, such as buttock size, were clearly changed in the side perspective. This confirmed the importance of a PC analysis in which covariation of body parts in both front and side images was determined.

2-D anthropometric measurements, original images. We measured the real 2-D anthropometric measures of the AdoBSD subjects (n = 160). A multivariate analysis with subject age and BMI as covariates revealed a significant effect of subject gender [F(13,144) = 11.133, p < .001] on a number of measures including virtual (i.e., image-derived) height, shoulder width, leg length, waist, belly and thigh width (Figure 6).

2-D anthropometric measurements, morphed images. The 2-D anthropometric measures were also used to quantify physical changes induced in the body images by the AdoBSD. Change was described as the percent change relative to real (i.e., nonmorphed) measures calculated for the 160 adolescents in the AdoBSD. These changes are calculated as slopes in order to identify the rate of change as a function of the amount of distortion introduced, the latter defined by the standard deviation of the mean of each PC. Slopes were calculated for each PC for all 14 anthropometric measures. These results are summarized in Table 4.

BMI characterization of body image morphing. Although the slopes described above provide detailed numerical values identifying whether certain body parts grow larger or smaller with changing distortion levels,

### Table 1A

<table>
<thead>
<tr>
<th>Tag-Point</th>
<th>Picture Side</th>
<th>Body Part</th>
<th>$M$ (cm)</th>
<th>CI (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Left</td>
<td>Small toe</td>
<td>0.32</td>
<td>0.19-0.45</td>
</tr>
<tr>
<td>2</td>
<td>Left</td>
<td>Big toe</td>
<td>0.29</td>
<td>0.23-0.35</td>
</tr>
<tr>
<td>3</td>
<td>Left</td>
<td>Medial ankle</td>
<td>0.45</td>
<td>0.26-0.64</td>
</tr>
<tr>
<td>4</td>
<td>Left</td>
<td>Medial calf</td>
<td>1.00</td>
<td>0.63-1.34</td>
</tr>
<tr>
<td>5</td>
<td>Left</td>
<td>Knee</td>
<td>1.01</td>
<td>0.72-1.29</td>
</tr>
<tr>
<td>6</td>
<td>Left</td>
<td>Medial proximal thigh</td>
<td>0.72</td>
<td>0.43-1.00</td>
</tr>
<tr>
<td>7</td>
<td>Left</td>
<td>Medial proximal thigh</td>
<td>0.69</td>
<td>0.48-0.91</td>
</tr>
<tr>
<td>8</td>
<td>Left</td>
<td>Knee</td>
<td>1.98</td>
<td>1.54-2.41</td>
</tr>
<tr>
<td>9</td>
<td>Left</td>
<td>Medial calf</td>
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<td>0.85-1.61</td>
</tr>
<tr>
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<td>Left</td>
<td>Medial ankle</td>
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<td>0.32-0.59</td>
</tr>
<tr>
<td>11</td>
<td>Left</td>
<td>Big toe</td>
<td>0.22</td>
<td>0.15-0.29</td>
</tr>
<tr>
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<td>0.25</td>
<td>0.17-0.33</td>
</tr>
<tr>
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<td>Left</td>
<td>Lateral ankle</td>
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<td>0.26-0.66</td>
</tr>
<tr>
<td>14</td>
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<td>Lateral calf</td>
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<td>0.87-1.73</td>
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<tr>
<td>15</td>
<td>Left</td>
<td>Lateral distal thigh</td>
<td>1.07</td>
<td>0.47-1.67</td>
</tr>
<tr>
<td>16</td>
<td>Left</td>
<td>Finger</td>
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<td>0.23-0.38</td>
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<tr>
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<td>0.54-0.91</td>
</tr>
<tr>
<td>18</td>
<td>Left</td>
<td>Waist</td>
<td>0.79</td>
<td>0.52-1.06</td>
</tr>
<tr>
<td>19</td>
<td>Left</td>
<td>Hip midpoint</td>
<td>0.91</td>
<td>0.66-1.16</td>
</tr>
<tr>
<td>20</td>
<td>Left</td>
<td>Hip upper quarter</td>
<td>0.95</td>
<td>0.67-1.22</td>
</tr>
<tr>
<td>21</td>
<td>Left</td>
<td>Hip lower quarter</td>
<td>0.98</td>
<td>0.68-1.29</td>
</tr>
<tr>
<td>22</td>
<td>Left</td>
<td>Breast</td>
<td>1.89</td>
<td>1.48-2.31</td>
</tr>
<tr>
<td>23</td>
<td>Left</td>
<td>Collarbone</td>
<td>0.88</td>
<td>0.64-1.13</td>
</tr>
<tr>
<td>24</td>
<td>Left</td>
<td>Shoulder</td>
<td>1.51</td>
<td>1.04-1.99</td>
</tr>
<tr>
<td>25</td>
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<td>Shoulder</td>
<td>1.62</td>
<td>1.15-2.09</td>
</tr>
<tr>
<td>26</td>
<td>Left</td>
<td>Collarbone</td>
<td>1.25</td>
<td>0.94-1.56</td>
</tr>
<tr>
<td>27</td>
<td>Left</td>
<td>Breast</td>
<td>2.38</td>
<td>1.84-2.92</td>
</tr>
<tr>
<td>28</td>
<td>Left</td>
<td>Waist</td>
<td>0.97</td>
<td>0.64-1.31</td>
</tr>
<tr>
<td>29</td>
<td>Left</td>
<td>Lateral proximal thigh</td>
<td>0.70</td>
<td>0.44-0.96</td>
</tr>
<tr>
<td>30</td>
<td>Left</td>
<td>Hip midpoint</td>
<td>0.97</td>
<td>0.58-1.36</td>
</tr>
<tr>
<td>31</td>
<td>Left</td>
<td>Hip upper quarter</td>
<td>0.87</td>
<td>0.42-1.31</td>
</tr>
<tr>
<td>32</td>
<td>Left</td>
<td>Hip lower quarter</td>
<td>0.83</td>
<td>0.62-1.04</td>
</tr>
<tr>
<td>33</td>
<td>Left</td>
<td>Finger</td>
<td>0.22</td>
<td>0.15-0.29</td>
</tr>
<tr>
<td>34</td>
<td>Left</td>
<td>Lateral distal thigh</td>
<td>0.91</td>
<td>0.68-1.13</td>
</tr>
<tr>
<td>35</td>
<td>Left</td>
<td>Lateral calf</td>
<td>1.39</td>
<td>1.01-1.77</td>
</tr>
<tr>
<td>36</td>
<td>Left</td>
<td>Lateral ankle</td>
<td>0.42</td>
<td>0.34-0.51</td>
</tr>
</tbody>
</table>

### Table 1B

<table>
<thead>
<tr>
<th>Tag-Point</th>
<th>Body Part</th>
<th>$M$ (cm)</th>
<th>CI (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Upper back</td>
<td>1.94</td>
<td>0.91-2.96</td>
</tr>
<tr>
<td>2</td>
<td>Lower back</td>
<td>1.05</td>
<td>0.79-1.31</td>
</tr>
<tr>
<td>3</td>
<td>Posterior hip</td>
<td>0.54</td>
<td>0.31-0.76</td>
</tr>
<tr>
<td>4</td>
<td>Posterior proximal thigh</td>
<td>1.47</td>
<td>1.13-1.80</td>
</tr>
<tr>
<td>5</td>
<td>Posterior distal thigh</td>
<td>1.56</td>
<td>0.93-2.19</td>
</tr>
<tr>
<td>6</td>
<td>Posterior mid thigh</td>
<td>1.54</td>
<td>1.13-1.94</td>
</tr>
<tr>
<td>7</td>
<td>Posterior calf</td>
<td>1.00</td>
<td>0.65-1.34</td>
</tr>
<tr>
<td>8</td>
<td>Heel</td>
<td>0.55</td>
<td>0.42-0.68</td>
</tr>
<tr>
<td>9</td>
<td>Right foot small toe</td>
<td>0.21</td>
<td>0.16-0.25</td>
</tr>
<tr>
<td>10</td>
<td>Right foot big toe</td>
<td>0.26</td>
<td>0.21-0.30</td>
</tr>
<tr>
<td>11</td>
<td>Anterior distal thigh</td>
<td>1.47</td>
<td>0.78-2.16</td>
</tr>
<tr>
<td>12</td>
<td>Anterior proximal thigh</td>
<td>1.39</td>
<td>1.05-1.73</td>
</tr>
<tr>
<td>13</td>
<td>Anterior mid thigh</td>
<td>1.19</td>
<td>0.79-1.60</td>
</tr>
<tr>
<td>14</td>
<td>Anterior hip</td>
<td>1.30</td>
<td>0.88-1.73</td>
</tr>
<tr>
<td>15</td>
<td>Anterior belly</td>
<td>0.76</td>
<td>0.41-1.12</td>
</tr>
<tr>
<td>16</td>
<td>Right breast</td>
<td>1.08</td>
<td>0.74-1.41</td>
</tr>
<tr>
<td>17</td>
<td>Finger</td>
<td>0.41</td>
<td>0.26-0.56</td>
</tr>
<tr>
<td>18</td>
<td>Head</td>
<td>0.62</td>
<td>0.46-0.79</td>
</tr>
</tbody>
</table>
they do not provide a global outlook of change as defined by BMI. A significant positive correlation was found between the real BMI values of the 160 AdoBSD subjects and calculated total body-volume \([r = .585, p < .001; F(1,158) = 82.16, p < .001]\)—see Figure 7]. Based upon this linear relationship, the changes in BMI induced by the AdoBMT were calculated from the virtual body-volume, and the ranges of these virtual BMI induced by each PC are graphically presented in Figure 8. All PCs showed a significant cubic relationship between virtual BMI and the degree of distortion \((p < .001)\).

**BEHAVIORAL VALIDATION OF THE AdoBMT**

**Method.** All experimental protocols were granted ethics approval under the provisions of the Research Ethics Board of the Montreal Neurological Institute and Hospital. Healthy adult volunteers (18–46 years) were recruited from the Montreal community through local advertisements. Informed consent was obtained for all participants. All subjects included in the study reported no history of or current serious medical condition. A total of 72 subjects (38 females) were recruited for the study. Two female subjects were excluded following testing as they reported suffering from a prior psychiatric illness. One female was excluded as she halted testing due to physical illness. A final total of 69 healthy subjects were included in the analysis (35 females, 34 males). The mean age and BMI were: females: 22.71 years \((\pm 0.58)\); males: 23.74 years \((\pm 0.58)\). Independent samples \(t\) tests revealed no significant effect of gender for subject age and BMI \((p > .05)\). The AdoBSD was divided into eight stimuli categories as defined by gender, the median age of the AdoBSD (i.e., 13 years) and the median BMI of each gender–age category. A different randomly selected combination of eight AdoBSD children (i.e., one from each category) was chosen for each subject in order to ensure maximum sampling of the AdoBSD. For each AdoBSD child, real images in front and side views were used. Front and side body images were also morphed with PC2, PC4 and PC5 and with \(\pm 0.1, \pm 0.3\) and \(\pm 0.5\) levels of distortion with the estimated BMI of the morphed bodies ranging from 16.5–24.1 kg/m\(^2\). PC1 was not selected as it morphs significantly the height of the body, a factor of no experimental interest to the authors. PC3 was also not used as we discovered that warping in the knee region did not provide realistic body images. Thus, the remaining three PCs (PC2, PC4 and PC5) that accounted for the most model variation were selected. Although it would have been ideal to include also PCs 6–8, the duration of such an experiment was deemed excessive and taxing for the subjects, potentially jeopardizing the quality of the acquired data. Consequently, subjects were presented with a total of 304 different body images (288 morphed images [8 AdoBSD children \(\times\) 2 views \(\times\) 3 PCs \(\times\) 6 distortion levels] plus 16 real images [8 AdoBSD children \(\times\) 2 views]) with each image repeated six times.

All images were randomly presented for 1,000 msec followed by a 250-msec interstimulus interval. The "oddness" scale was then presented on the screen for a maximum of 2,000 msec during which subjects were requested to make their response. An intertrial interval of 250 msec was used.

**Results**

For the real images, a repeated measures ANOVA was conducted with one between-subjects variable (subject gender) and four within-subjects variables; the latter included image gender, image view (front vs. side), age of the image (high \([\geq 13\ yr]\) vs. low \([< 13\ yr]\) and BMI of the image (high vs. low). A significant three-way interaction between image view, image BMI and subject gender was found \([F(1,67) = 5.307, p < .05]\) (Figure 9A). Subsequent simple main effects analysis and pairwise comparisons with Bonferroni correction revealed that female subjects rated low BMI images as significantly less odd than high BMI images \((p < .05)\); note that this finding was observed even though our healthy adult volunteers were being shown the real images of adolescent bodies.

For the morphed images, a repeated measures ANOVA was completed with subject gender as a between-subjects variable and five within-subjects variables; the latter included image gender, image view (front vs. side), type of distortion (PC2, PC4, PC5), direction of distortion (large vs. small morph size) and amount of distortion

<table>
<thead>
<tr>
<th>Tag-Point</th>
<th>Anthropometric Measure</th>
<th>Pearson's Correlation (r)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Virtual height</td>
<td>.997</td>
<td>.00</td>
</tr>
<tr>
<td>2</td>
<td>Sitting height</td>
<td>.985</td>
<td>.00</td>
</tr>
<tr>
<td>3</td>
<td>Leg length</td>
<td>.989</td>
<td>.00</td>
</tr>
<tr>
<td>4</td>
<td>Shoulder width/biacromial breadth</td>
<td>.922</td>
<td>.03</td>
</tr>
<tr>
<td>5</td>
<td>Hip width A/bicristal breadth</td>
<td>.988</td>
<td>.00</td>
</tr>
<tr>
<td>6</td>
<td>Hip width B/bicristal breadth</td>
<td>.981</td>
<td>.00</td>
</tr>
<tr>
<td>7</td>
<td>Left calf width</td>
<td>.967</td>
<td>.00</td>
</tr>
<tr>
<td>8</td>
<td>Right calf width</td>
<td>.966</td>
<td>.00</td>
</tr>
<tr>
<td>9</td>
<td>Left thigh width</td>
<td>.902</td>
<td>.00</td>
</tr>
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<td>Right thigh width</td>
<td>.973</td>
<td>.00</td>
</tr>
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<td>Waist</td>
<td>.995</td>
<td>.00</td>
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<td>Hip</td>
<td>.982</td>
<td>.00</td>
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<td>Side thigh</td>
<td>.978</td>
<td>.00</td>
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</table>
Figure 5. Principal component analysis-based body morphing. On the left, line drawings indicate changes in body size and shape with sequential addition of distortion to the \((x, y)\) coordinates of the mean location of the body tag-points. On the right, a female subject is morphed using PC4 in the front and side perspectives. Images represent (from left to right) \(-0.4, -0.2, +0.2,\) and \(+0.4\) SD from the mean of each respective PC.

\(\pm 0.1, \pm 0.3, \pm 0.5\) SD of the mean of the PC. ANOVA revealed a significant five-way interaction between all of the within-subjects variables \(F(4,268) = 5.661, p < .001\). This complex interaction, however, would likely fail to provide any substantial insight into the data. Consequently, we examined the significant three-way interaction between our three variables of interest (i.e., amount of distortion, type of distortion and image view) \(F(4,268) = 11.660, p < .001\) (Figure 9B). Simple main effects analysis and pairwise comparisons with Bonferroni correction revealed a significant effect of image view, with the front view showing significantly higher mean scores (i.e., higher “oddness”) than the side view for all conditions \((p < .05)\). In addition, an effect of principal component was revealed whereby PC2 morphing was found to result in significantly lower (i.e., less odd) mean scores than PC4 or PC5 across all conditions \((p < .05)\). Finally, a significant distortion effect was found only for PC4 and PC5 and not PC2, with higher mean scores associated with greater introduced distortion \((p < .05)\).

In order to determine the relative degree of “oddness” associated with morphed body images, 95% confidence intervals of the mean scale scores for the real front and side photographs were used as statistical baseline values. Mean scale scores for 0.3 and 0.5 SD of distortion for PCs 4 and 5 were found to be greater than the maximum interval level.

**GENERAL DISCUSSION AND CONCLUSIONS**

We have described a novel age-specific body-morphing tool that transforms 2-D (front and side view) images of adolescent bodies according to the natural covariations across individual body parts. PCA of landmarks positioned on the 320 images constituting our database revealed eight primary principal components that characterized 96.3% of the co-variation between body tag-points across male and female subjects. This analysis also revealed covariation between tag-points within and between front and side views. These PCs, when applied to real body images using our image-morphing software, resulted in the standardized distortion of various body dimensions including the body’s height, and the size of the shoulders, waist, hip, thighs, belly, and calves. These changes in body-shape and size were generated such that specific body parts were morphed simultaneously as dictated by the variation present in the subject population of our database. We then characterized the resulting image distortion using both a 2-D anthropometric system and an estimation of BMI from a calculation of total body-volume.
A multivariate analysis revealed a significant effect of subject gender on 2-D anthropometric measurements. Significant differences between males and females were reported for the following anthropometric measures: virtual height, leg length, shoulder width, thigh width, waist width, and belly width ($p < .05$).

The use of a point distribution model based upon PCA of the covariance of the tag-point coordinates was successful in that it effectively simulated global changes in adolescent morphology. The PCA results clearly showed that body-part changes rarely occurred in isolation. When morphing body images, covariances must be incorporated if realism is to be maintained and if reliable assessment of perceptual changes is to be achieved.

The AdoBMT was characterized using two quantitative methods including a 2-D (i.e., image-derived) anthropometric system and an estimated BMI. Analysis of the real BMI for all 160 AdoBSD subjects revealed a significant linear relationship between the real BMI and body-volume estimated from the 2-D images. This linear relationship allowed us to estimate BMI for all morphed body images. The results clearly indicated that changes
Table 4

<table>
<thead>
<tr>
<th>ID</th>
<th>Body Part</th>
<th>PC1</th>
<th>PC2</th>
<th>PC3</th>
<th>PC4</th>
<th>PC5</th>
<th>PC6</th>
<th>PC7</th>
<th>PC8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Virtual height</td>
<td>92.91</td>
<td>-2.50</td>
<td>5.59</td>
<td>9.90</td>
<td>-5.31</td>
<td>-7.33</td>
<td>1.15</td>
<td>-1.08</td>
</tr>
<tr>
<td>2</td>
<td>Sitting height</td>
<td>78.45</td>
<td>-6.31</td>
<td>8.73</td>
<td>28.93</td>
<td>-18.89</td>
<td>-21.72</td>
<td>-2.49</td>
<td>-2.81</td>
</tr>
<tr>
<td>3</td>
<td>Leg length</td>
<td>107.42</td>
<td>1.27</td>
<td>2.48</td>
<td>-9.00</td>
<td>8.19</td>
<td>6.95</td>
<td>4.77</td>
<td>0.64</td>
</tr>
<tr>
<td>4</td>
<td>Shoulder width</td>
<td>99.04</td>
<td>0.22</td>
<td>38.32</td>
<td>36.64</td>
<td>-9.61</td>
<td>10.53</td>
<td>-4.17</td>
<td>4.81</td>
</tr>
<tr>
<td>5</td>
<td>Hip A</td>
<td>91.40</td>
<td>-0.75</td>
<td>52.63</td>
<td>51.88</td>
<td>-25.87</td>
<td>35.82</td>
<td>5.76</td>
<td>-9.37</td>
</tr>
<tr>
<td>6</td>
<td>Hip B</td>
<td>74.68</td>
<td>5.35</td>
<td>78.25</td>
<td>39.48</td>
<td>-32.05</td>
<td>68.73</td>
<td>6.46</td>
<td>-8.52</td>
</tr>
<tr>
<td>7</td>
<td>Left calf</td>
<td>90.50</td>
<td>-7.19</td>
<td>60.14</td>
<td>57.16</td>
<td>-36.85</td>
<td>53.64</td>
<td>-7.49</td>
<td>4.89</td>
</tr>
<tr>
<td>8</td>
<td>Right calf</td>
<td>98.08</td>
<td>10.77</td>
<td>62.58</td>
<td>49.93</td>
<td>-44.27</td>
<td>49.03</td>
<td>-6.08</td>
<td>2.62</td>
</tr>
<tr>
<td>9</td>
<td>Left thigh</td>
<td>73.87</td>
<td>-15.46</td>
<td>30.76</td>
<td>50.50</td>
<td>-70.69</td>
<td>58.22</td>
<td>6.44</td>
<td>-14.33</td>
</tr>
<tr>
<td>10</td>
<td>Right thigh</td>
<td>75.43</td>
<td>-11.63</td>
<td>29.22</td>
<td>48.58</td>
<td>-62.12</td>
<td>56.08</td>
<td>2.14</td>
<td>-13.09</td>
</tr>
<tr>
<td>11</td>
<td>Waist</td>
<td>66.30</td>
<td>1.76</td>
<td>74.10</td>
<td>26.38</td>
<td>-8.05</td>
<td>46.61</td>
<td>-2.90</td>
<td>2.91</td>
</tr>
<tr>
<td>12</td>
<td>Hip</td>
<td>91.86</td>
<td>4.27</td>
<td>54.78</td>
<td>46.45</td>
<td>-27.25</td>
<td>38.33</td>
<td>0.76</td>
<td>-4.92</td>
</tr>
<tr>
<td>13</td>
<td>Belly</td>
<td>42.85</td>
<td>-0.15</td>
<td>98.00</td>
<td>20.50</td>
<td>-14.95</td>
<td>78.43</td>
<td>11.37</td>
<td>5.17</td>
</tr>
<tr>
<td>14</td>
<td>Side thigh</td>
<td>91.11</td>
<td>-6.41</td>
<td>88.26</td>
<td>45.91</td>
<td>-48.29</td>
<td>88.14</td>
<td>-2.85</td>
<td>-8.87</td>
</tr>
</tbody>
</table>

Note—The rate of change in each anthropometric measure is expressed as a slope [i.e., relative percent change (%)] over standard deviation of the mean of each PC.

in body-shape induced by the AdoBMT translated into tangible changes in BMI. The range of BMI change induced by each PC was proportionate to the amount of variation accounted for in the point distribution model by each PC. Standardized morphing changes were also found to result in a significant cubic relationship with changes in estimated BMI. In spite of linear changes induced in the anthropometric measures used to calculate total body-volume, cubic changes in estimated BMI would be produced by virtue of the volume calculation. Although the precision of the BMI estimation may be broad in nature, the results clearly demonstrate that body size and shape changes induced by the AdoBMT may be characterized quantitatively using a biologically relevant descriptor.

The unique nature of our PCA-based analyses provides us with various types of morphed images. For example, PCI induces a gross distortion of body-shape, driven primarily by the subject's height, whereas the other PCs offer an opportunity for a subtler distortion with emphasis on particular body regions (i.e., lower body) while always respecting the natural variations between body parts. In addition, the degree of distortion may be manipulated by varying the standard deviation of the mean of the PC used in the distortion. The amount of distortion introduced is entirely arbitrary; for practical reasons, we selected a standard-deviation range of -0.8 to +0.8. With this range of distortion across all eight PCs, the maximum BMI range of the morphed images was 12.52-51.79 kg/

![Figure 7. Linear regression of BMI and total body-volume. A significant linear relationship between BMI and total cylindrical body-volume \( F(1,158) = 82.16, p < .001 \) was established. Linear regression analysis determined a function \( \text{BMI} = 12.379 + 101.699 \times \text{total cylindrical body-volume} \) to estimate the BMI of a given body.](image)
Figure 8. Estimated mean BMI of morphed body images. Significant cubic relationships were established between estimated BMI and level of distortion for PC1 (A) and PCs 2–8 (B), \( p < .05 \).

m². Thus, with a database of 160 adolescent images and the flexibility in our distortion technique, we generated a library of nearly 41,000 body images for use as stimuli. Researchers can make use of this established library of images along with the associated age, gender and BMI information to create generalized body perception experiments for large groups of participants. In addition, the AdoBMT software can be used to create individualized stimuli for each study participant given that a standardized source image (Figure 1) is available.

Which PCs and what amount of distortion should be used in future experiments? With respect to the different PCs, PC1 accounts for the greatest amount of variation in our model with a total of 82.9%. Although PC1 induces gross changes in all of the anthropometric measures, the single largest change is in the height of the body. As such, it is unlikely that PC1 will prove useful in future experiments. In contrast, PCs 2–8 account for variation ranging from 0.37%–6.0%. These PCs account for much less of the variation in our model; yet,
they also allow for greater variety in the combination of body parts that are manipulated. Although PC2 accounts for 6.0% of the variation, it does not appear to generate much in the way of physical changes in body size and shape. This is likely due to the fact that PC2 models changes in subject stance. Variation in subject stance would not be reflected in the anthropometric measures of Table 4 and thus, we see little in the way of changes in body-shape and size.

Given the inherent difficulties with PCs 1 and 2, we will likely focus on the remaining PCs (i.e., 3–8) for use in future experiments. As indicated in Table 3, PCs 3–8 account for 0.37%–2.5% of the variation in the model. In spite of these low values, one should note that use of these

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Figure 9. A significant three-way interaction between subject gender, image perspective and image BMI on mean scale scores was detected. (A) Female subjects rated low BMI body images as significantly less odd than high BMI images ($p < .05$). A three-way interaction between image view, type of distortion, and amount of distortion was found to be significant. (B) Front images were found to be more odd than side images ($p < .05$). PC2 morphed images were found to be less odd than PC4 or PC5 images ($p < .05$). A significant distortion effect was also noted with greater distortion associated with a higher mean score (i.e., more odd) ($p < .05$).
five PCs still results in substantial BMI changes. In fact, PCs 3 and 4 both induce an 11-point change in BMI when using a standard deviation range from -0.8 to +0.8. These PCs appear to affect primarily body size and shape in the lower body; this may be particularly useful as prior studies have revealed that both adolescent males and females overestimate the size of their body parts including the waist, buttocks and thighs (Bergstrom, Stenlund, & Svedjehall, 2000; Halmi, Goldberg, & Cunningham, 1977).

We believe that the AdoBSD and AdoBMT represent novel morphing tools with three key advantages over many of the techniques currently in use (e.g., paper-and-pencil tools). These advantages include: (1) the use of high-fidelity digital images, (2) the use of adolescent bodies as the source, and (3) the use of a morphing procedure that accounts for natural covariations between individual body parts and body views.

The use of a computerized morphing technique is of particular importance as morphing allows the real-time production of individualized body-image stimuli, the flexibility to generate body images with a wider range of size and the ability to quantify the scale of measurement. This enhances the tools' use in clinical populations. For example, the morphing technique allows researchers to generate extremely large bodies for use with the obese and extremely thin bodies for use with anorexic patients. Although body morphing may appear quite complex, use of the image library will be made easy with online access and a simple online interface with which researchers can identify desired images using various parameters (i.e., gender, age, height, weight).

In the perceptual-realism experiment, we asked a group of healthy adult subjects to rate the “oddness” of both real and morphed images selected from the AdoBSD. We found linear distortion effects for PC4 and PC5 but not PC2; for the former two PCs, greater introduced distortion was associated with higher “oddness” scores. This effect indicates that adult subjects are able to detect subtle changes in body-shape and size induced by morphing real images using these two PCs. The fact that PC2 failed to display any significant distortion effect for both front and side views is not surprising as this PC appears to model changes in waist, buttocks and thighs (Bergstrom, Stenlund, & Svedjehall, 2000; Halmi, Goldberg, & Cunningham, 1977).

Another key finding lies in the relative degree of “oddness” of the morphed images when compared to the ratings of the real images. Healthy adult volunteers found body images distorted with 0.3 and 0.5 SD of PC4 and PC5 to be clearly more odd than the real images. It is clear that 0.5 SD of distortion is extreme; this level of distortion may, nevertheless, prove to be useful in clinical populations.

The primary goal of the behavioral experiment was to characterize the perceptual realism of the morphed images and consequently, aid in the selection of appropriate morphing parameters. Nevertheless, analysis of mean scale scores revealed interesting effects of subject gender and image BMI with respect to the real body images. In particular, the females rated low BMI images as significantly less odd than high BMI images. Although these findings are not definitive in their ability to establish perceptual biases among the adults with respect to real body perception, they are consistent with published studies investigating body dissatisfaction and ideal body perception in both adolescents and adults. Numerous studies using various techniques have reported that adolescent and adult females select an ideal body size that is smaller or thinner than the perceived size of their real body (Brodie, Bagley, & Slade, 1994; Fallon & Rozin, 1985; Fernandez, Probst, Meermann, & Vandereycken, 1994; Kostanski, Fisher, & Gullone, 2004; Rozin & Fallon, 1988; E. R. Sands & Wardle, 2003; R. Sands et al., 2004; Zellner, Harner, & Adler, 1989). In contrast, males have been found to select a larger or more muscular body size as their ideal when compared to their perceived body size (Brodie, Slade, & Riley, 1991; Cohn et al., 1987; Pope et al., 2000). Overall, some studies have also found that females report more body dissatisfaction when compared to males (Altabe & Thompson, 1993; Kostanski et al., 2004). These findings, however, are often dependent on the BMI of the subject in question (Kostanski et al., 2004). Taken as a whole, these ideal and body dissatisfaction studies support the results reported in the current study.

Our implicit experimental design has produced significant findings in spite of the fact that our volunteers were asked no explicit questions regarding the shape and size of the presented body images. The very fact that the results appear to be in accordance with published results supports the validity of our tools.

Here, we have described the development, characterization and validation of a novel adolescent body-shape database and adolescent body morphing tool. Although we have carefully described the development and biological characteristic of the AdoBSD and AdoBMT, it would be of interest to compare this novel method with existing techniques by utilizing multiple techniques within a single study to explore the potential limitations or differences in an applied setting.

For future studies with healthy adolescents, the existing database of real and morphed images could be used such that participants would not have to pose for a source image but rather be simply matched to an existing child in the database. Once this matching has been achieved, the real and morphed images of the AdoBSD child could be used as experimental stimuli. In order to facilitate the widespread use of this novel tool, we provide free access to the images used in the current study. This will allow an interested researcher to select and download real and morphed images for their studies. The image selection is facilitated by a matching algorithm: a researcher inputs participants’ age, height and/or weight and is provided with those AdoBSD images that best match those parameters. These tools may be accessed via the University of Nottingham Brain and Body Centre Web site (www.brainbody.nottingham.ac.uk/).

Although the AdoBSD and AdoBMT pertain to healthy adolescent children, the methodology of image acquisi-
tion, body tagging, and body morphing can also be applied to other populations of interest, such as obese adults or athletes. In order to re-create these tools for other specific populations, participants would have to pose for source pictures in similar bodysuits and researchers would have to body-tag and individually morph these images.

Ultimately, future studies can now utilize these tools to explore the underlying cognitive processes of healthy adolescent body perception, as well as clinical conditions such as obesity and eating disorders.

**AUTHOR NOTE**

Funding was provided by the Canadian Institutes for Health Research and the Santa Fe Institute Consortium. The authors acknowledge the contributions of Louis Collins, Zdenka Pausova, and Rhonda Amsel. Correspondence regarding this article should be addressed to T. Paus, Brain and Body Centre, University of Nottingham, University Park, Nottingham NG7 2RD, England (e-mail: tomas.paus@nottingham.ac.uk).

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(Manuscript received June 12, 2006; revision accepted for publication September 1, 2006.)
Appendix G

Authorship Waiver

Chapters 3, 4