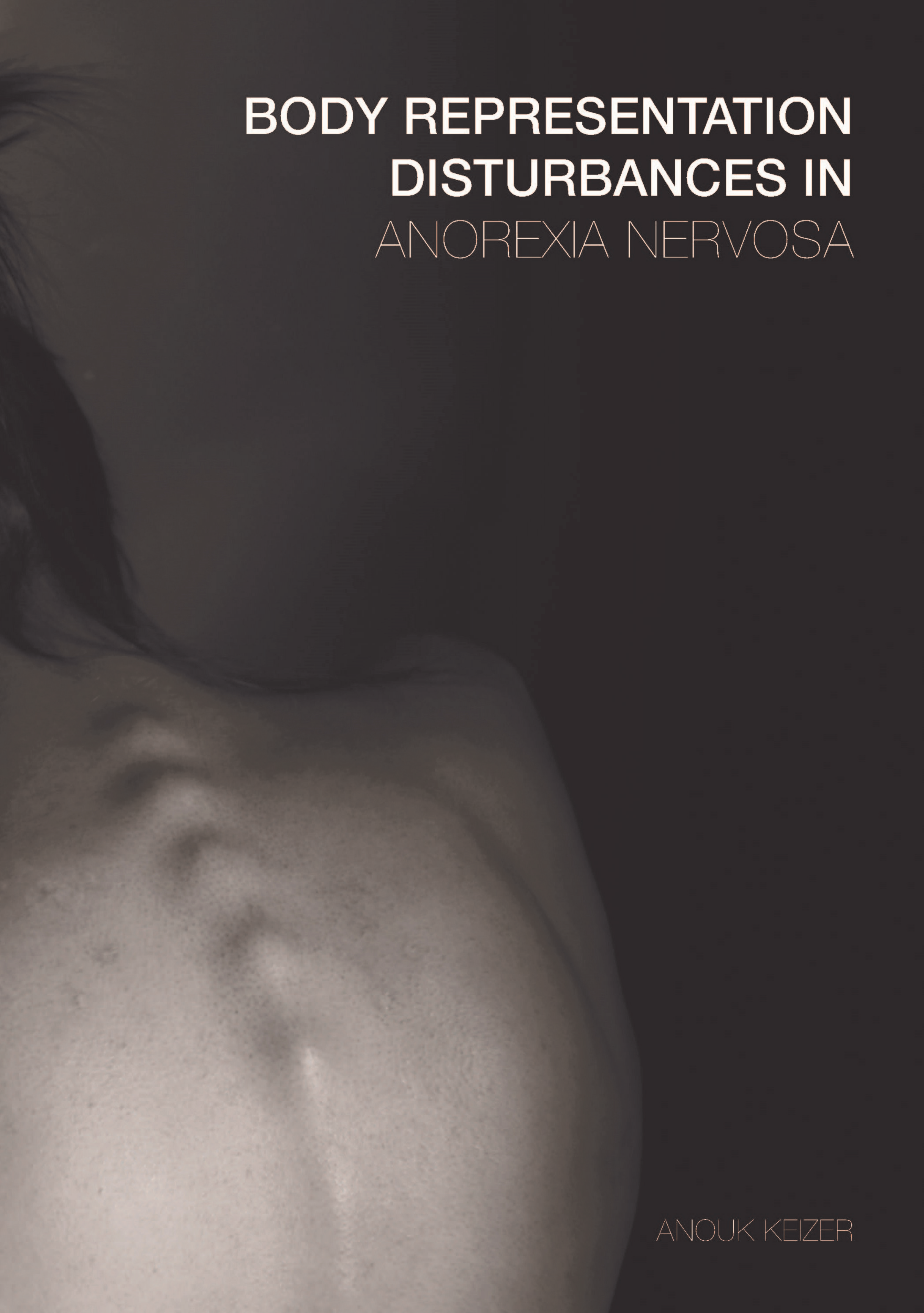
BODY REPRESENTATION DISTURBANCES IN ANOREXIA NERVOSA



ANOUK KEIZER

Body representation disturbances in anorexia nervosa

Lichaamsrepresentatie stoornissen in anorexia nervosa
(met een samenvatting in het Nederlands)

Proefschrift

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Anouk Keizer
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Promotoren: Prof. dr. H.C. Dijkerman
Prof. dr. M.A.M. Smeets
Prof. dr. A.A. Van Elburg

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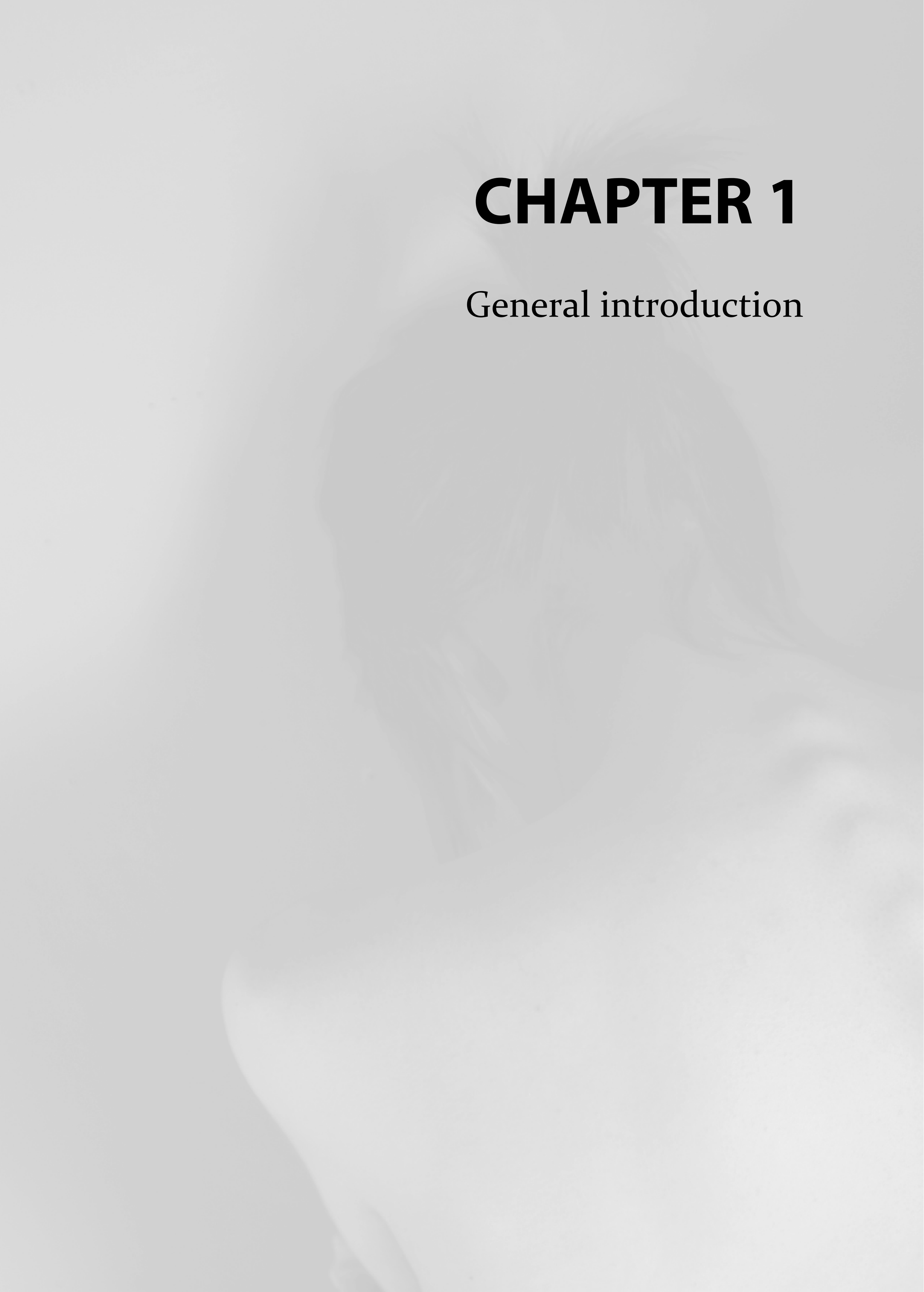
CONTENTS

Voor mijn ouders



CHAPTER 1

General introduction

Patient B.C.

19 years old, 5-HAVO student
1.67 cm, 50.4 kg, BMI 18.1
was 38.5 kg, BMI 13.8, at start of treatment 8 months ago

When asked to try to explain what it means to "feel fat" she responded with the following:

"I feel fat all day long. I feel fat and fat rolls all over my body, and especially after I eat something it feels as if my face, stomach and legs are blown up.

Because of these feelings I constantly feel a need to hide myself, and cover up my legs, stomach and face. When I'm around others, for example when we're sitting on a couch, or when we're eating, it feels as if I take up too much space. In these situations I feel big and plump, like there is too much of me in a group.

I find it horrible to feel this way. It makes me want to lie in bed all day long and avoid social interactions. I just don't want to do anything anymore because I'm ashamed of how fat I look and afraid to face others.

Feeling fat prevents me from living like I used to do. I avoid the things I used to like, because I'm ashamed of how I look. Feeling fat makes me want to lose weight, which triggers my eating disorder. It definitely works against me in the process of beating my eating disorder."

1.1. Background

During the past years I have encountered many girls, and the occasional boy, diagnosed with anorexia nervosa (AN). Like patient B.C. most of them were skinny. Others were extremely thin, and some did not even really differ that much from myself. What is striking about AN is that when I would ask any patient to describe the same girls I have encountered, they would probably categorize the skinny and extremely thin girls similar to how I just did. However, they would most likely place themselves at the opposite end of the continuum, and regardless of their actual weight, inform me about the fact that they are actually the odd one out: That they are one of the very few girls in the eating disorder clinic that is not skinny, but rather a bit chubby or even too fat.

It is in my opinion both fascinating and saddening to see that AN patients often seem to be stuck in some sort of parallel universe in which they cannot perceive and experience their body size realistically. This results in significant functional impairments *and* complicates treatment. The focus of this thesis is therefore on creating a better understanding of the disturbed experience of body size in AN.

In the introduction of this thesis I will first give a brief overview of AN in the light of symptoms and characteristics. I will then discuss body image according to the traditional perspective on this topic. Following upon this I will address the neuropsychological/cognitive neuroscientific perspective on how the body is represented in the brain. Subsequently, I will place the disturbed experience of body size in AN in this cognitive neuroscientific context and discuss how this may benefit understanding of body size experience in AN.

1.2. Anorexia Nervosa – An overview

The Diagnostic and Statistical Manual of Mental Disorders IV-TR (DSM-IV-TR, APA, 2000 see Table 1) defines AN as a mental disorder in which being underweight and maintaining an underweight state is paradoxically coupled with a distorted experience of body weight and shape. Although AN is probably the most well-known eating disorder its prevalence in the community is relatively low (for reviews see e.g. Hoek, 2006; Smink et al., 2012). Recent data suggest a lifetime prevalence of about 0.6 percent for young females (Stice et al., 2013), while other eating disorders such as Bulimia Nervosa and Binge Eating Disorder are suggested to have a prevalence of about 2.6 and 3.0 percent, respectively (Stice et al., 2013). Still, in both scientific research and the media AN tends to attract more attention than other eating disorders. This may be related to the clearly emaciated physique of AN patients, which underlines its severity.

The severity of the disorder may also be inferred from the low success rates of treatment. Multiple studies have shown that a substantial portion of AN patients remains chronically ill (e.g. Fichter et al., 2006; Steinhausen, 2002), while estimates of full recovery revolve around roughly 50 percent (e.g. Steinhausen, 2002; van Son et al., 2010). A standardized mortality rate estimated between about 4 and 10 percent (for reviews see e.g. Arcelus et al., 2011; Hoek, 2006; Nielsen et al., 1998; Smink et al., 2012) places AN among the most severe psychosomatic/psychiatric disorders (see e.g. Harris and Barraclough, 1998).

Table 1. DSM-IV-TR Diagnostic criteria for anorexia nervosa

A	Refusal to maintain body weight at or above a minimally normal weight for age and height (e.g. weight loss leading to maintenance of body weight less than 85% of that expected; or failure to make expected weight gain during period of growth, leading to body weight less than 85% of that expected).
B	Intense fear of gaining weight or becoming fat, even though underweight.
C	Disturbance in the way in which one's body weight or shape is experienced, undue influence of body weight or shape on self-evaluation, or denial of seriousness of the current low body weight.
D	In postmenarcheal females, amenorrhea, i.e. the absence of at least three consecutive menstrual cycles (amenorrhea is defined as periods occurring only following hormone, e.g. estrogen, administration).
Restricting type: during the current episode of anorexia nervosa the person has not regularly engaged in binge-eating or purging behaviour (i.e. self-induced vomiting or the misuse of laxatives, diuretics, or enemas).	
Bing-eating/purging type: during the current episode of anorexia nervosa the person has regularly engaged in binge-eating or purging behaviour (i.e. self-induced vomiting or the misuse of laxatives, diuretics, or enemas).	

Note. Adapted from American Psychiatric Association: Diagnostic and Statistical Manual of Mental Disorders, 4th ed., text rev. Washington DC, American Psychiatric Association, 2000.

AN typically develops during (early) adolescence in females (see e.g. Hoek, 2006; Smink et al., 2012; Stice et al., 2013), with only about 7 percent of the AN patients being male (e.g. van Son et al., 2010). The main symptoms of AN (i.e. maintaining a dangerously low body weight by restricting food intake, while being unable to perceive and experience the own body as emaciated as it in reality is) ensure that AN patients go to great lengths to achieve their unattainable goal of becoming extremely thin. AN patients behave obsessively and ritualistically in terms of (not) eating and exercise, which results in significant functional impairments. Patients may become so consumed by their illness that they no longer feel motivated to invest time in school, work, and/or social relationships and activities. In addition, prolonged self-induced food-deprivation and starvation may not result in an unwillingness to engage in activities per se, but also in an inability to do so. In time the body becomes worn out and the patient faces (severe) physical complications, such as, anemia, low pulse and blood pressure, irregular heartbeat, heart failure, dehydration, numbness in the extremities, hypothermia, ulcers, kidney stones, kidney failure, osteoporosis and weakened muscles (see e.g. Casiero and Frishman, 2006; Misra and Klibanski, 2006; Papadopoulos et al., 2009; Sharp and Freeman, 1993).

As for causes and risk factors for developing AN, numerous studies have been conducted, examining the disorder from different perspectives. Studies focusing on for example brain mechanisms (e.g. Kaye et al., 2009), hormone-functioning (e.g. Bailer and Kaye, 2003), genetics (e.g. Klump and Gobrogge, 2005), cognitive functioning (e.g. Zakzanis et al., 2010), emotional processing (e.g. Safer and Chen, 2011), personality traits (e.g. Lilenfeld et al., 2006), psychosocial factors (e.g. Keel and Forney, 2013; Troop and Treasure, 1997), and cultural factors (e.g. Keel and Klump, 2003) all identified certain risk factors for AN. However none of these studies was able to identify a single cause for developing AN.

Virtually all researchers agree that AN is a highly complex and heterogeneous disorder, in which multiple factors interact with each other (for a review see e.g. Stice, 2002). In this thesis I will contribute to a better understanding of AN by specifically focusing on one of the most puzzling and intriguing symptoms of the disorder: AN patients, although they are dangerously underweight, persistently experience their body as bigger than it actually is. Traditionally, this phenomenon is referred to as a *body image disturbance* (see e.g. Cash and Deagle, 1997; Smeets et al., 1997), i.e. the actual shape and size of the body do not match the picture patients have of themselves in their head. Body image disturbances in AN may manifest themselves through wearing body-concealing clothes, avoidance of certain people or situations (ranging from swimming pools to birthday parties), body checking or avoidance (e.g. in the mirror), excessive need for social feedback, and rituals regarding appearance correction (e.g. physical exercise; Cash and Hrabosky, 2004). Experiencing body image disturbances can result in significant functional impairment. It is for example not uncommon that patients refuse to go outside because they are extremely ashamed of how fat they look and do not want to burden others with such a sight.

The experience of the own body as bigger than it actually is has been proposed to be a central factor in the development and maintenance of AN (Killen et al., 1996; Stice, 2002; Stice and Shaw, 2002). It has been found to be a consistent predictor of onset (e.g. Farrell and Shafran, 2006; Thompson et al., 1995), and high levels of body image disturbance at the beginning of treatment predict poorer treatment response (e.g. Button, 1986; Freeman et al., 1985; Leon et al., 1985). In addition, relapse is predicted by the severity of body image disturbance at pretreatment, during treatment, and posttreatment (Button, 1986; Carter et al., 2004; Freeman et al., 1985). Further, it has been found that body image related symptoms remain after otherwise successful treatment (Exterkate et al., 2009).

Taken together, the disturbed experience of body size plays a central role in the etiology, maintenance and relapse of AN. Insight in the nature and extent of this disturbance in body image is crucial to fully understand AN pathology as well as to design effective treatment approaches.

1.3. "Body image" in anorexia nervosa – Traditional view

A widely used definition of body image in clinical psychology presents the concept as a two-folded dimension, consisting of an affective body image and a perceptual body image. Traditionally, body image disturbances in AN were investigated by clinical psychologists and psychiatrists. Much of this research was inspired by perceptual psychology and psychophysics (see e.g. Slade and Russell, 1973). This has led to the development of so-called Body Size Estimation (BSE) tasks. During the late 1980's, BSE tasks were considered the golden standard for assessing body image disturbances in AN. In BSE tasks participants were asked to estimate their body width by adjusting for example a photograph or video image of their own body (see e.g. Cash and Deagle, 1997; Farrell et al., 2005; Skrzypek et al., 2001; Smeets, 1997; Smeets et al., 1997). Such tasks are still used in recent studies (Miyake et al., 2010; Mohr et al., 2007; Mohr et al., 2010; Waldman et al., 2013). Results from most BSE studies show that AN patients selectively overestimate their body size, but do not have a general deficit in size perception (see e.g. Cash and Deagle, 1997; Slade and Russell, 1973; Smeets, 1997).

What is however problematic about BSE paradigms is that they are rooted in perceptual psychology and psychophysics, so that judging the size of bodies is considered no different from judging the size of objects. Thereby overlooking that a body is not a neutral object, but surrounded by emotions and attitudes, *especially* in AN patients, rendering bodily affect an important dimension that might influence bodily percepts. Thus, even though typical results from BSE tasks imply overestimation of body size in AN, this does not necessarily allow for the conclusion that the visual representation of the body is disturbed. BSE tasks may not solely assess the visual aspects of body image, rather they may elicit a response based on an integration of body attitudes and visual (mental) images of the body (e.g. Farrell et al., 2005; Smeets, 1997; Stewart and Williamson, 2004). This understanding has hindered the field of body image distortion research in AN. It was unclear how to incorporate body attitudes in existing theories on body image distortion, and how body attitudes exactly related to body perception (Hsu and Sobiewicz, 1991).

A second problem that has impacted the field of body image distortion in AN is that, following perceptual psychology and psychophysics, research was dominated by visual perception of the body. However, in contrast to visually perceiving an object, the body can only be directly visually perceived in full using a mirror. Importantly, the body is not only seen, but also perceived through other senses, such as touch. In addition, dominance of the visual modality in traditional literature is in conflict with what clinical observations show. For example, clinical observations (e.g. Espeset et al., 2011) indicate that patients refer to their disturbed body image as something they feel from their body, rather than only something they see in the mirror, or thoughts they have. It thus seems crucial to capture how it is that the *feeling* of being fat persists, even when visual perception and cognition have become aligned with reality. Or, as one of our AN patients once stated "*Deep down I know that I cannot be fat. But I believe that your brain can deceive you in many ways. I cannot trust my senses, because they keep telling me that I'm fat. I wish I could though, I wish that for once my feeling would tell me that I'm ok*."

Taken together, traditional body image views and methodological approaches may have hampered building a full understanding of the disturbed experience of body size. They focused almost exclusively on the perceptual body image in the visual domain and barely on the affective body image, although due to the design of traditional methodology it is likely that the latter has biased the results from studies focusing on the perceptual body image (for reviews see e.g. Cash and

Deagle, 1997; Farrell et al., 2005; Skrzypek et al., 2001; Smeets et al., 1997). More recent developments in the areas of neuropsychology and cognitive neuroscience offer a novel perspective, if not a paradigm shift. Applying these insights and methodologies to AN could result in an increased understanding of AN patients' distorted experience of body size, and possibly offer an explanation for this phenomenon. Specifically, adopting a cognitive neuroscientific viewpoint ensures that the representations of the body are seen as separate from object representations, taking into account the influence of body related emotions and cognitions. Second, it acknowledges the importance of senses other than vision (e.g. touch, proprioception) in body perception and experience. I believe that adopting a cognitive neuroscientific perspective on the disturbed experience of body size in AN more accurately captures the way in which AN patients themselves describe their "distorted body image" and at that the same time it offers possibilities for using novel experimental designs to assess body size disturbance.

1.4. Mental body representations – A cognitive neuroscience approach

The cognitive neuroscience/neuropsychological point of view offers a more strict and better structured definition of the representation of the body in the brain than the concept "body image" that is used in traditional literature on disturbed body size experience in AN (see Figure 1). Concerning the latter, the underlying assumption exists that AN patients experience distorted body size at the level of cognition (thinking they are fat) and visual (mental) perception (seeing and/or imagining their body as fat, see e.g. Cash and Deagle, 1997; Skrzypek et al., 2001; Smeets et al., 1997). However, the brain continuously receives body-related input from different sensory modalities. This information can be related to how the body looks, but also to for example where the body is located or how it is touched. Following a cognitive neuroscientific line of reasoning, the brain processes this primarily multimodal information and integrates it into an coherent and abstract higher order representation of the body (see e.g. de Vignemont, 2010; Dijkerman and de Haan, 2007; Gallagher, 2005; Haggard and Wolpert, 2005; Paillard, 1999; Serino and Haggard, 2010). This body representation thus stores different kinds of bodily information from multiple senses. Most relevant for the present thesis is that it includes detailed abstract information on body size. Besides metric aspects of the body, it for example also stores the location of the body in space, and the configuration of different body parts forming a consistent whole. As the representation of the body contains so much bodily information is deemed crucial in a wide array of processes and behaviours, for example recognizing the own body, bodily semantics, identifying bodily threats, performing motor-sequences, tool-use, identifying the affective state the body is in. As such, body representations play a key role in an individuals' sense of ownership and agency over the own body, which is crucial in forming a sense of "being yourself" as well as being able to perform (goal-directed) behaviours (e.g. de Vignemont, 2010).

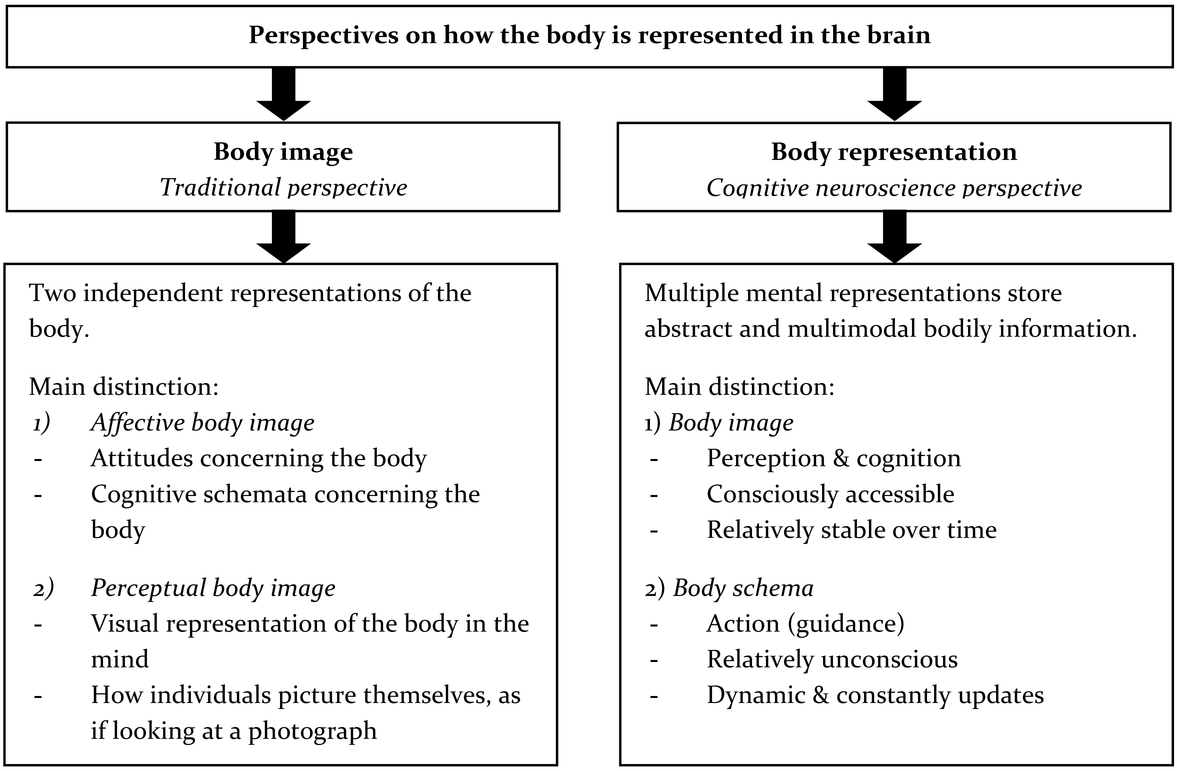


Figure 1. Schematic overview of different perspectives on the representation of the body in the brain outlined in this thesis.

In neuropsychological and cognitive neuroscientific literature considerable debate exists on the number of representations of the body in the brain, the exact function(s) of each representation, and the basis on which they should be distinguished (e.g. de Vignemont, 2010; Dijkerman and de Haan, 2007; Gallagher, 2005; Haggard and Wolpert, 2005; Paillard, 1999; Schwoebel and Coslett, 2005). A dominant view has its roots in the perception – action distinction. According to this model two main body representations can be distinguished: The *body image* and the *body schema* (de Vignemont, 2010; Dijkerman and de Haan, 2007; Gallagher, 2005; Haggard and Wolpert, 2005; Head and Holmes, 1911; Paillard, 1999). The body image can be defined as a perception-oriented, consciously accessible representation of the body that also includes semantic and emotional beliefs regarding the body (Gallagher, 2005). In contrast, the body schema is thought to operate on a relatively unconscious level, and is suggested to be mainly involved in regulating sensory-motor processes such as posture and movement (e.g. Gallagher, 2005).

Studies with neurological patients suffering from for example peripheral deafferentation (no proprioceptive functioning and sense of touch below the neck, Gallagher and Cole, 1995), apraxia (loss of ability to perform goal-directed movents, Buxbaum et al., 2000; Schwoebel and Coslett, 2005), (visual) neglect (unawareness of one side of the body, Marshall and Halligan, 1988; Preston and Newport, 2011b) and autotopagnosia/somatotopagnosia (inability to localize body parts, Guariglia et al., 2002) suggest that the body image and body schema operate independent from each other. Double dissociation studies have been reported on patients with numbsense, who have lost proprioceptive functioning and sense of touch on the right side of their body after (sub)cortical lesions. Interestingly, these patients, although they cannot detect or localize touch on the right side of their body, are capable of making a fairly accurate pointing movement to the touched location with their unaffected hand (Paillard et al., 1983; Rossetti et al., 1995). This implies that different pathways exist for relatively conscious perceptual processing of sensory input (body image) and relatively unconsciously using sensory input to guide actions (body schema, see also Anema et al., 2009).

As indicated above, disturbance in the representation of the body can result in significant impairments. More closely related to AN, there are several conditions in which specifically bodily experience is affected in terms of size, shape, and appearance of the body. For example, Body Dysmorphic Disorder (distorted perception of appearance of (a part of) the body; Feusner et al., 2010), Body Integrity Identity Disorder (desire to amputate a healthy limb; Sedda, 2011), Cotard Syndrome (delusion of being dead, putrefying or having lost internal organs and blood; Young et al., 1992), supernumerary limb (awareness of a nonexistent limb; McGonigle et al., 2002), phantom limb (awareness of an amputated limb; Flor et al., 2006), and macro-/microsomatotognosia (experiencing the body as disproportionately big/small; Sandyk, 1998). Although in itself these disorders are highly interesting, they are much more rarely encountered than AN. Still, in many cases researchers have taken both a psychiatric as well as a neuro(psycho)logical approach in investigating disturbed body experience in these disorders (e.g. Sedda, 2011). Such an approach has been adopted less frequently in AN.

1.5. Mental body representations & anorexia nervosa

In recent years some researchers have taken an interest in investigating body size experience in AN using methodologies rooted in neuropsychology and (cognitive) neuroscience (e.g. Fassino et al., 2002; Kaye et al., 2009; Miyake et al., 2010; Mohr et al., 2007; Mohr et al., 2010; Nico et al., 2010; Sachdev et al., 2008; Seeger et al., 2002; Urgesi et al., 2012; Wagner et al., 2003). Such studies offer valuable insight into brain functioning of AN patients. For example functional imaging studies have identified abnormal processing of visual bodily information in AN patients compared to both healthy controls (e.g. Uher et al., 2005), and recovered AN patients (e.g. Kaye, 2008), in brain areas and neural networks crucial for visual body perception, such as the extrastriate body area (EBA) and fusiform body area (FBA; e.g. Suchan et al., 2010; Urgesi et al., 2012; Vocks et al., 2010a; Vocks et al., 2010b). Further, the posterior parietal cortex has been implicated in (perceptual aspects of) the distorted experience of body size in AN (see e.g. Frank et al., 2004; Gaudio and Quattrocchi, 2012; van Kuyck et al., 2009).

There is still an emphasis on visual processing in these studies, which in part may be the result of how body representation disturbances in AN are depicted in traditional literature, but it might also be related to methodology. Structural and functional imaging techniques such as fMRI, MRI, PET and SPECT (see e.g. Frank et al., 2004; Gaudio and Quattrocchi, 2012; van Kuyck et al., 2009) require passive paradigms, which are more suitable for assessing visual processing than for example motor performance. The results from these studies have not led to clear-cut, uniform conclusions, which may be in part caused by the use of different definitions of what constitutes as “body image” across studies. Moreover, most studies used small heterogeneous samples, without distinguishing between different subtypes of AN. Imaging studies in which differences between acute and recovered AN patients were of interest used different definitions of recovery, which may have contributed to inconsistent results as well.

Recently several (meta analytic) reviews have been published on imaging studies in AN populations. Despite a number of inconsistencies, the main conclusion is that weight concerns and (construction of) distorted body representations in AN are related to alterations in the anterior cingulate cortex (ACC) and parietal areas. The ACC has also been suggested to play an important role in emotional aspects of processing bodily information in AN (Frank et al., 2004; van Kuyck et al., 2009). However, there is no direct single fiber connection between these two brain regions. A more recent review therefore proposes that the insula, temporal cortex and possibly the amygdala may link the parietal cortex and the ACC (Gaudio and Quattrocchi, 2012). As for the more cognitive aspects of body representations (i.e. thoughts and attitudes about the body), the prefrontal cortex (PFC) and insula have been implicated in AN (Gaudio and Quattrocchi, 2012).

The brain areas identified in AN patient studies show similarities with brain areas implicated in body representation disturbances observed in neuro(psycho)logical patients. In this field there is not necessarily agreement on the exact neural networks involved in body representations and the precise functional contributions of certain brain areas either. General consensus exists however on the crucial link between higher order representations of the body/bodily experiences and the posterior parietal cortex and the insular cortex (see e.g. Dijkerman and de Haan, 2007).

Besides imaging studies mainly focusing on affective and visual aspects of body representation in AN, there are also a few studies that have focused on other aspects of sensory processing using neuro(psycho)logical tasks (e.g. Grunwald et al., 2002; Nico et al., 2010). For example deficits in haptic perception of relief patterns were shown in both currently ill and recovered AN patients (Grunwald et al., 2001), implying that AN patients have more difficulties in transferring haptic/tactile signals to a spatially accurate visual image. Disturbed multisensory integration has been found in AN as well (Case et al., 2012; Eshkevari et al., 2012; Grunwald et al., 2002; Guardia et al., 2012b). Multisensory integration refers to how the brain integrates different streams of incoming information from different senses into a coherent and uniform percept. In light of the representation of the body, the brain continuously receives bodily information from different senses, such as vision, touch, and proprioception. Multisensory integration ensures amongst others that individuals experience their body as a coherent whole in terms of bodily configuration and spatial location. Depending on the context or situation, a specific source of information can be dominant during multisensory integration. For example, visual information of where the hands are located is more important and/or informative in a situation in which the hands are actually visible (e.g. turning off a light switch), compared to a situation where the hands are less visible (e.g. turning on a light switch in a dark room). On the one hand, studies on multisensory integration suggest that AN patients' representation of their body is more malleable than that of healthy females as they are more susceptible to bodily illusions inducing changes in bodily configuration (Eshkevari et al., 2012). On the other hand, they imply that AN patients' weighting of different types of sensory input is altered (Case et al., 2012).

The latter may be related to findings of decreased interoceptive awareness and processing of interoceptive information in AN (see e.g. Pollatos et al., 2008). Interoceptive awareness refers to the extent to which an individual is able to recognize and monitor internal bodily processes. A popular example is monitoring of one's heart-beat. Furthermore, interoceptive awareness includes recognizing the affective (e.g. increased heart rate in stressful situations) and physiological state the body is in (e.g. body temperature, and feelings of hunger, pain, and fatigue). AN patients were, although not consistently (Lautenbacher et al., 1990), found to have elevated heat thresholds (Papezova et al., 2005), meaning that they had difficulty recognizing stimuli as being painfully hot. In addition AN patients showed altered insular response in pain anticipation (Strigo et al., 2013). In contrast to healthy females, in AN patients no relation was found between the physiological and affective stress responses (Miller et al., 2003). Furthermore, AN patients process signals of taste, hunger and satiety different than healthy females (Nakai and Koh, 2001; Wagner et al., 2008).

Taken together these studies indicate that AN patients show abnormal performance in a variety of tasks in which representations of the body are assumed to play a role. It is likely that not only processing of visual body information and bodily cognitions is disturbed in AN, but processing of other sensory input as well. What is particularly relevant to AN pathology is processing of sensory input related to body size, as AN patients have a disturbed experience of the size of their body. Such metric information on body dimensions is used in constructing a metric representation of the body, i.e. an (abstract) representation of the size of the body and its parts. None of the studies mentioned above directly linked multimodal metric aspects of body representation to distorted experience of body size in AN. It is therefore yet unclear whether AN patients have an internal metric representation of the size of their body that is indeed bigger than the body's objective measures. The current thesis aims to investigate this issue. I believe it is important to assign a central role to metric representations of body size when investigating the disturbed experience of the body in AN, as these metric representations are most directly linked to how the body is experienced in terms of size and shape.

Metric bodily information can affect perception (body image) as well as action (body schema). As for body image, object-constancy helps individuals to build representations of objects around them based on the size of their own body. For example, it was shown that by experimentally manipulating visual body size, the haptic perception of external objects (Haggard and Jundi, 2009) and stimuli pertaining the body (Taylor-Clarke et al., 2004) is altered as well. In relation to body schema, in order to move around in the world efficiently and safely, individuals need to store information on the size of their body in the brain. Action-guidance is not exclusively based on where the body is in space, so (a part of) it can be moved from location A to location B. Such movements also involve (unconscious) knowledge on which actions the body affords given its size (e.g. Warren and Whang, 1987). If AN patient's bodily information is indeed stored and/or processed differently compared to healthy individuals, this may reflect on a full range of body image and body schema tasks, and might not necessarily be strictly related to visual (mental) and emotional processing of bodily information.

1.6. Outline of this thesis

Given the cognitive neuroscientific definition of mental body representations being multimodal, it is surprising that research with AN patients has mainly focused on the distorted experience of body size in terms of cognitions and visual (mental) processing. The main aim of the present thesis is to extend existing research findings so a more complete view on the scope of body representation disturbances in AN emerges. The present thesis consists of three sections. Section one deals with body image disturbances in AN with a specific focus on the metric representation of the body involved in somatosensory processing (Chapter 2 through 4). Section two focuses on body schema disturbances in AN, specifically on how a disturbed experience of body size can affect the way individuals move around in space (Chapter 5 and 6). In section three plasticity of body representation is discussed in the light of bodily illusions (Chapter 7).

Chapter 2 presents a methodological study in which a new paradigm for assessing metric aspects of body representation is evaluated in healthy subjects. According to previous research, making a size estimation of the distance between two stimuli pressed on the skin involves activation of a metric representation of body size (Spitoni et al., 2010). Generally, such tactile distance estimation tasks involve a comparison between distances presented to two separate body parts (e.g. Spitoni et al., 2010; Taylor-Clarke et al., 2004). Here participants were asked to estimate the distance on a single body part, which gives specific information on the mental representation of the size of that body part. In **Chapter 3** two main research questions are addressed. First, whether AN patients' visual mental image of their body is distorted, and second, whether body image distortions in AN extent to the tactile domain. Notably, the first research question is addressed using a paradigm in which no visual information is presented to the participants, resulting in an assessment of the visual mental representation of the body in the brain that is not directly biased by attitudinal and emotional influences (e.g. Smeets et al., 2009). The second research question, addressing possible disturbances in tactile body image, is investigated using the tactile size estimation paradigm presented in Chapter 2. Subsequently, **Chapter 4** focuses on possible explanations for tactile body image disturbances in AN. Specifically the questions whether low-level somatosensory input reaches the brain in a distorted way in AN patients, or whether a disturbed metric representation of body size is more likely to result from higher order processing is addressed.

Chapter 5 presents a study in which a novel approach to the assessment of walking through apertures is evaluated in healthy subjects. When walking through an aperture individuals use a representation of the size of their body to guide their actions (e.g. de Gelder et al., 2008; Warren and Whang, 1987). This chapter focuses on whether awareness of the aim of the study influences action performance. **Chapter 6** focuses on body schema disturbances in AN, specifically the question whether AN patients' disturbed experience of body size also affects bodily movements during locomotion, using the paradigm presented in Chapter 5.

In **Chapter 7** a study focusing on plasticity of body representation in AN is discussed. The aim of this chapter is twofold, first, it is investigated whether AN patients have a higher malleability of body representation than healthy participants, and second, whether it is possible to experimentally change how body size is perceived. A bodily illusion in which ownership over a fake limb is induced (see e.g. Botvinick and Cohen, 1998; Eshkevari et al., 2012) is used to address the former. Afterwards participants were asked to estimate the size of their body part, which enabled assessment of whether ownership over a new (fake) limb also affects metric representations of body size.

CHAPTER 2

Tactile size estimation task: Assessment of metric body representation with clinical implications

Anouk Keizer
Monique A.M. Smeets
Albert Postma
Chris Dijkerman

Article in prep

Abstract

Here we present a quick and easy method for *directly* assessing metric aspects of mental body representations in a specific body part. Forty participants (20 male) completed the Tactile Estimation Task (TET) and a pressure detection task (Von Frey filaments). In the TET, blindfolded participants judged distances between two simultaneously presented tactile stimuli by separating their thumb and index finger, or by responding verbally. The results showed no effect of gender, site of stimulation (left/right arm), or response hand (left/right). TET size estimations were more accurate than verbal size estimates. The former did not correlate with pressure detection, implying that different processes are used in both tasks. We suggest that the TET can be easily used in a clinical setting when a quantification of suspected body representation disturbances is required. Implications for using the TET in clinical populations are discussed (e.g. in anorexia nervosa or chronic pain).

1. Introduction

The cortical representation of the human body in the brain is quite different from the configuration of the body parts that make up the actual human body. In the somatosensory cortex (SI) the body is represented according to sensitivity and density of skin receptors, resulting in differences in the amount of cortical neurons associated with a certain body part. For example, the fingers and lips take up a larger, or more densely innervated, cortical area than the back or upper leg. This difference in magnitude is related to the functional use of the body part, as individuals for example use their fingers, but not their upper legs, in explorative movements that require a high level of tactile discriminative ability. The distorted representation of the body in SI does not affect a healthy individuals' internal experience of the size and shape of their body parts. It is suggested that object constancy is responsible for this, i.e. a higher order representation of the body is used in rescaling this distorted input from SI (Taylor-Clarke et al., 2004). This so-called *mental body representation* contains amongst others abstract, multimodal information regarding metric properties of the body and its parts (e.g. de Vignemont, 2010; Dijkerman and de Haan, 2007; Gallagher, 2005; Paillard, 1999; Serino and Haggard, 2010).

Having a robust measure for how the mental body representation is organized, fosters both fundamental research into theoretical aspects of the mental body representation as well as insight in its role in certain clinical populations, something that might be of help for diagnostics and clinical effect studies. There are several clinical populations in which one of the (main) symptoms is a disturbance in the mental representation of the body (see also de Vignemont, 2010). For example, anorexia nervosa (AN) patients are by definition underweight, but experience and visually perceive their body as if they are overweight (Cash and Deagle, 1997). In patients suffering from body dysmorphic disorder (BDD) main pathology revolves around obsessive and ritualistic behaviour regarding an imagined deficit in one's appearance (Cororve and Gleaves, 2001). body identity integrity disorder (BIID) is defined by a mismatch between the actual body anatomy and the experienced bodily identity, resulting in an intense desire for amputation of one or more limbs (Sedda, 2011). Besides psychiatric disorders, there are neurological conditions in which body representation disturbances are of relevance. For example, cerebral damage after a stroke may result in somatoparaphrenia, i.e. the inability to recognize one or more limbs contralateral to the side of the lesion as belonging to oneself, but ascribing its identity to someone else (Bottini et al., 2002). Further, in complex regional pain syndrome (CRPS) and chronic back pain patients the affected body part is perceived different from its actual size and shape (Lotze and Moseley, 2007; Moseley, 2008).

In most of the conditions discussed above, the focal point of the disturbed representation of the body or parts of the body lies in the distorted experience of its size and shape. In order to fully understand the nature of these disturbances an assessment of specifically the metric aspects of the mental representation of the body is warranted. Here we present a tactile size estimation task that can be used for this purpose.

To date most studies that focus on (disturbed) perceptual experiences of the body or a specific part of the body related to somatosensory processing use two-point discrimination or pressure/vibration detection (e.g. Aoyama et al., 2012; Faris et al., 1992; Giummarra et al., 2011; McCabe et al., 2006; Moseley, 2008; Moseley et al., 2008b; Pauls et al., 1991; Peltz et al., 2011; Vartiainen et al., 2008). However, according to Spitoni and colleagues (2010) a mental body representation is not assessed with such tasks. They showed unique involvement of specific brain regions over activity in SI and SII only when judging the *size* of touch (i.e. distance between to touches) to the skin, not during lower level perception, such as merely judging whether touch on the skin was present. In order to estimate the size of an object touching the skin, metric information about the size of the body is needed. Skin receptors crucial in lower level somatosensory processing do not convey such information directly (Spitoni et al., 2010). Therefore, information about what was felt on the skin needs to be compared to, and integrated with metric information of the touched body part, which is stored in a higher order mental body representation (de Vignemont et al., 2005).

Currently, the most commonly used method to assess tactile size perception in healthy populations instructs participants to judge whether there is a difference in size between two (identical) stimuli presented on two separate body parts (e.g. de Vignemont et al., 2005; Spitoni et al., 2010; Taylor-Clarke et al., 2004). For example participants are asked to judge whether the distance between two tactile stimuli presented to their arm is larger or smaller than the (identical) distance presented to their thigh (Spitoni et al., 2010). Although this task involves judging the size of tactile stimuli, and thus supposedly involves the use of a higher order mental representation of body size (Spitoni et al., 2010), there are several reasons as to why this task may be inconvenient when studying clinical populations. First, tasks in which stimuli presented to different body parts have to be compared to each other involve a memory component. This may pose a problem in certain patient populations (i.e. stroke patients). More importantly, for some clinical populations it may be especially relevant to focus on the distorted representation of a single body part, or directly compare two body parts. For example, BDD patients perceive a certain aspect of their body in a disturbed way (e.g. nose or ears, Cororve and Gleaves, 2001). Although AN patients report an overall fatter experience of body size, they often have specific body parts that they worry about most in terms of fatness (e.g. abdomen or thighs). Also, CRPS patients experience their affected limb (often the hand/arm) as swollen in size (Moseley et al., 2008b; Peltz et al., 2011). Similarly, for other chronic pain patients the distorted experience of body size is limited to the painful body part (Lotze and Moseley, 2007; Moseley, 2008). It has even been shown that manipulating the size of a body part reduces pain experience in a patient with osteoarthritis of the hand (Preston and Newport, 2011a).

Here we validated a task that assesses the metric mental body representation of a *specific* part of the body. We designed a task in which participants were asked to *directly* estimate the distance between two tactile stimuli touching the skin of one body part, by separating their thumb and index finger. In addition we aimed at designing a task that is short, easy to administer and provides researchers and clinicians with flexibility to adjust the task in such a way that it is most relevant to their research question or the pathology of their patients. To explore the possibilities for adapting the task we varied the location of the stimuli (left vs right arm), response hand (left vs right hand), and asked a subset of the sample to make a verbal estimation of the distance between the stimuli touching their skin.

2. Methods

2.1 Participants

Twenty male and 20 female undergraduate students participated on the basis of informed consent. All participants were right-handed. Mean age was 22.25 (SD=2.55) years for males and 22.20 (SD=2.75) for females, $t(38)=-0.06$, $p=.953$.

2.2. Materials

2.2.1. Tactile Size Estimation

Tactile size estimation was measured with the Tactile Estimation Task (TET, based on Anema et al., 2008). In each trial blindfolded participants received two, above threshold, tactile stimuli to the forearm with a calliper (see Figure 1A). Stimuli were applied for one second. Participants estimated the distance between the two stimuli by separating their thumb and index finger (see Figure 1B). Three stimuli distances were included: 50, 60, and 70 mm. To ensure that participants would indeed be able to perceive the two stimuli as distinct, all three stimuli distances were larger than the two point discrimination threshold for the forearm (~40 mm; Weinstein, 1968). Each of the three distances was randomly presented five times, making a total of 15 trials.

Responses were recorded with a Wacom Bamboo Touchpad®, model CTH-661. Using a tailored MATLAB® (The MathWorks®) routine, the coordinates of the middle points of the thumb and index finger were recorded 100 times within each trial. For each recording the distance between the thumb and index finger was calculated. The average distance between the fingers over the 100 recordings within each trial constituted as the response (i.e. distance estimation) on a given trial.

As we aimed to design a task that can be adapted to the needs or limitations of certain clinical populations, four different conditions were included in a within subjects design; 1) *right congruent* in which stimuli were presented to the right arm and size estimations were made with the right hand; 2) *left congruent* in which stimuli were presented to the left arm and size estimations were made with the left hand; 3) *right incongruent* in which stimuli were presented to the right arm and size estimations were made with the left hand; 4) *left incongruent* in which stimuli were presented to the left arm and size estimations were made with the right hand. The order of the conditions was counterbalanced.

To further explore potential possibilities for adapting the TET to certain clinical populations, a subset of the sample (20 males) completed a verbal variant of the TET. This enabled us to investigate how manual size estimation differs from verbal size estimation. Blindfolded participants received tactile stimuli (identical to the procedures explained above) on their right forearm, and verbally estimated the size between the two stimuli in centimetres. Participants for example responded by saying "4.3 cm". Responses on the verbal TET were compared to manual distance estimations on the right congruent condition of the manual TET described above.

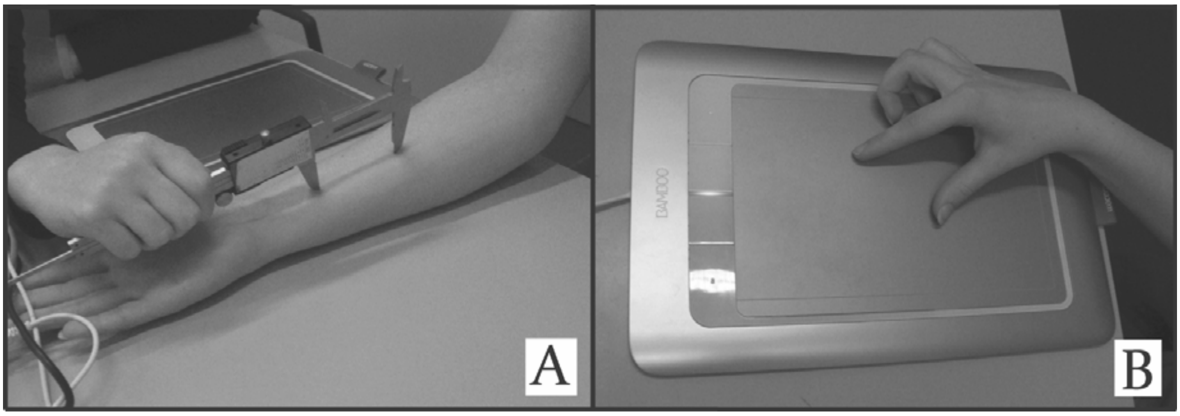


Figure 1. Tactile Estimation Task: Panel A shows the presentation of the tactile stimuli, panel B shows the distance estimation between the stimuli.

2.2.2. Pressure detection

A Von Frey (VF) pressure detection task was included to investigate whether the TET indeed required different processing than tasks associated with low level somatosensory processing (Spitoni et al., 2010). VF filaments (Touch-Test™ Sensory Evaluator from Stoelting Co) are thin nylon fibres with which pressure can be applied ranging from 0.008 till 300 grams force (e.g. Fruhstorfer et al., 2001; Weinstein, 1968). Blindfolded participants were instructed to report whether or not they perceived a stimulus. Participants placed their arm (palm up) on a table and a stimulus was presented to the forearm in 66 percent of the trials. Responses were recorded with a one up one down two-alternative forced choice staircase with five reversals (Wetherill and Levitt, 1965). The pressure detection threshold was calculated by averaging the filament of the last four reversals. The starting filament required a force of 0.40 gf (Park et al., 2001). Participants completed two conditions; 1) stimuli presented to the right arm; and 2) stimuli presented to the left arm. The order of the conditions was counterbalanced.

3. Results

3.1 Tactile size estimation - manual

As data from one of the male participants in the left congruent condition was missing, this participant was excluded from data analyses. Data was distributed normally, for a detailed overview of participants' distance estimations see Table 1.

Table 1. Mean distances estimations in the Tactile Estimation Task by distance, condition, and group.

	Females (n=20)		Males (n=19)		Total sample (n=39)	
	M	SD	M	SD	M	SD
50 mm						
Right congruent	51.51	15.87	50.84	24.27	51.18	20.12
Left congruent	53.40	22.21	55.73	22.74	54.54	22.19
Right incongruent	52.61	16.01	53.28	22.73	52.93	19.31
Left in congruent	49.98	17.69	48.48	21.80	49.25	21.08
60 mm						
Right congruent	61.69	13.19	56.24	18.82	59.04	16.20
Left congruent	62.83	19.22	58.80	21.73	60.87	20.31
Right incongruent	59.14	14.42	62.91	23.57	60.98	19.25
Left in congruent	57.74	17.73	56.04	26.89	56.91	22.37
70 mm						
Right congruent	65.76	14.78	68.45	23.00	67.07	19.01
Left congruent	70.67	17.18	68.44	23.16	69.59	20.07
Right incongruent	66.06	15.60	70.72	25.87	68.33	21.08
Left in congruent	64.87	17.07	66.74	26.11	65.78	21.67
All distances						
Right congruent	59.66	12.82	58.51	20.40	59.10	16.75
Left congruent	62.30	18.61	60.99	20.67	261.66	19.39
Right incongruent	59.27	14.04	62.30	22.70	60.75	18.58
Left in congruent	57.53	16.92	57.09	22.99	57.31	19.83
All distances						
All conditions	59.69	13.63	59.72	19.82	59.71	16.70

A mixed repeated measures ANOVA showed no distance*gender interaction $F(6,32)=0.14$, $p=.274$, while a main effect for distance (50 vs 60 vs 70 mm) was found $F(2,74)=73.96$, $p<.001$, indicating that as the presented stimuli distance increased, size estimates made by participants were larger as well, independent of gender. We therefore used the mean size estimation (i.e. mean size estimation over the 50, 60, and 70 trials) in subsequent analyses.

A mixed repeated measures ANOVA did not show a main effect of condition (right congruent vs right incongruent vs left congruent vs left incongruent), $F(1,37)=0.79$, $p=.381$, nor a main effect of gender (male vs female), $F(1,37)=0.00$, $p=.995$ (see Figure 2). No condition*gender interaction was found, $F(1,37)=0.21$, $p=.646$. Bonferroni corrected one sample t-tests showed that in neither condition size estimations deviated from the mean presented distance of 60 mm, $t_{right\_congruent}(39)=-0.39$, $p=.699$, $t_{right\_incongruent}(39)=0.54$, $p=.594$, $t_{left\_congruent}(39)=0.56$, $p=.799$, and $t_{left\_incongruent}(39)=-0.85$, $p=.403$.

Taken together these results imply that males and females made identical size estimations in each of the four conditions of the TET. In addition, participants performed equally well on each of the four conditions, and were able to accurately estimate the size of the presented distances.

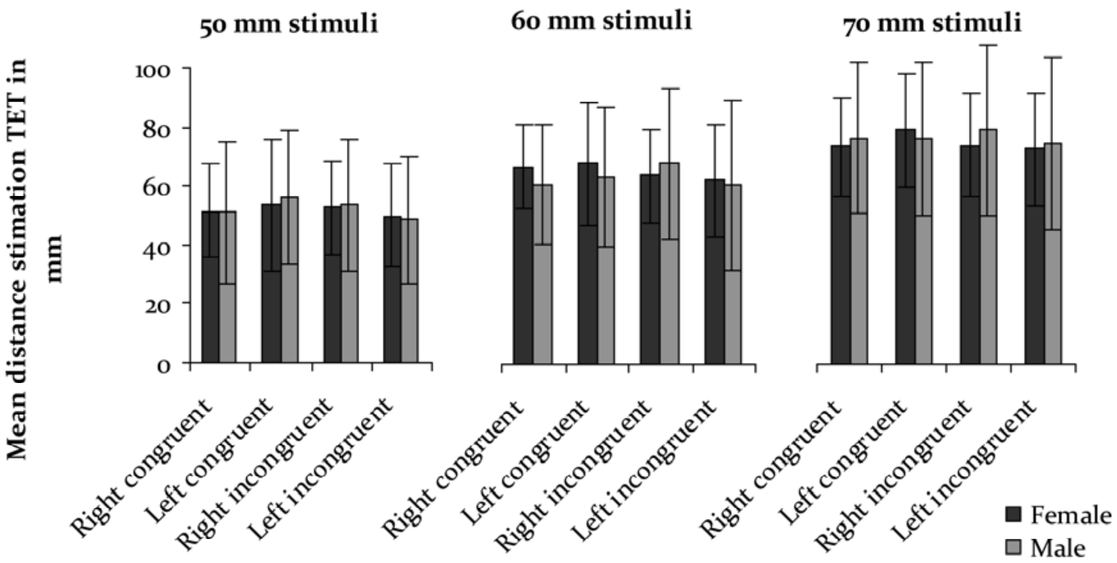


Figure 2. Distance estimations by gender and condition (on the X-axis) for 50 mm stimuli (left); 60 mm stimuli (middle); and 70 mm stimuli (right). Error bars depict the SD.

3.2 Tactile size estimation - verbal

Note that these analyses are based on n=20 (males only). Mean distance estimation was 40.99 (SD=24.30) in the verbal TET ($M_{TET\_50}=34.12$, SD=22.92; $M_{TET\_60}=40.43$, SD=23.01; $M_{TET\_70}=48.41$, SD=28.96), and 58.31 (SD=19.88) in the right congruent condition in the manual TET ($M_{TET\_50}=51.33$, SD=23.72; $M_{TET\_60}=56.04$, SD=18.35; $M_{TET\_70}=67.55$, SD=22.74) and.

A mixed repeated measures ANOVA showed a main effect for distance (50 vs 60 vs 70 mm), $F(2,38)=22.53$, $p<.001$, and no distance*condition (manual vs verbal) interaction, $F(2,38)=0.44$, $p=.648$, indicating that size estimates increased as stimuli size increased in both the manual and verbal TET (see Figure 3). More importantly, a main effect of condition was found, $F(1,19)=8.76$, $p=.008$, indicating that manual size estimates (i.e. made by separating the thumb and index finger) were larger than verbal size estimates (i.e. verbally reporting the tactile distance), independent of stimuli size (see Figure 3).

In addition, a Bonferroni corrected one sample t-tests showed that manual size estimates (M=58.31, SD=19.88) did not deviate from 60 (i.e. the mean stimuli distance), t(19)=-0.38, p=.708, while verbal size estimates (M=40.99, SD=24.30) were significantly smaller than 60 mm, t(19)=-3.50, p=.002. There was no significant correlation between manual and verbal size estimates, r(19)=.31, p=.183.

Taken together, manual size estimates of the distance between two tactile stimuli were more accurate than verbal size estimates of the same stimuli, and verbal estimates resulted in underestimation of the presented distance.

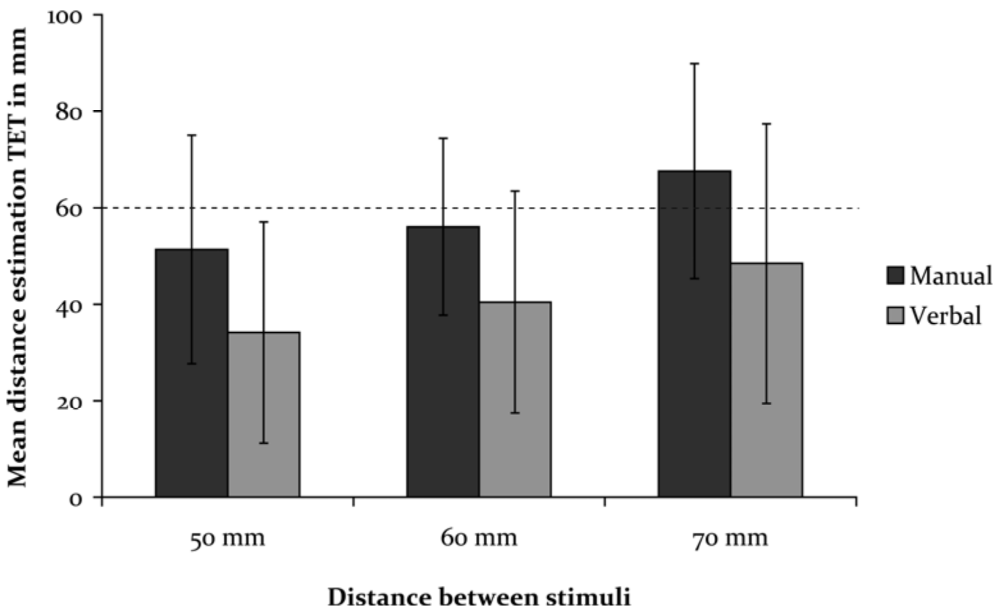


Figure 3. Results from the right congruent condition of the TET (males only) and verbal TET. The dashed line at 60 mm depicts an accurate distance estimation. Error bars depict the SD.

3.3 Pressure detection

Mean pressure detection threshold in the VF task was 0.33 (SD=0.13) for males (M_{right}=0.29, SD=0.11; M_{left}=0.36, SD=0.18) and 0.25 (SD=0.10) for females (M_{right}=0.25, SD=0.16; M_{left}=0.25, SD=0.07). A mixed repeated measures ANOVA showed no main effect for condition (right vs left arm), F(1,38)=1.58, p=.217, nor a condition*gender interaction, F(1,38)=2.20, p=.147. A main effect for gender was found, F(1,38)=5.11, p=.030, see Figure 4. These results show that females had a lower threshold for detecting stimuli on their forearm than males, regardless of the arm on which stimuli were presented. In other words females detected lighter touch on their forearm than males.

As the results of the TET and VF task showed no differences between the conditions, and to test whether the two tasks were in any case related, we correlated the mean TET score over all four conditions with the mean VF threshold for the left and right arm combined for males and females separately. The results showed that for both males and females there was no correlation between TET and VF ($r_{females}$=-.12, p=.601; r_{males}=-.05, p=.851), suggesting that the TET taps into different aspects of somatosensory information processing than the VF.

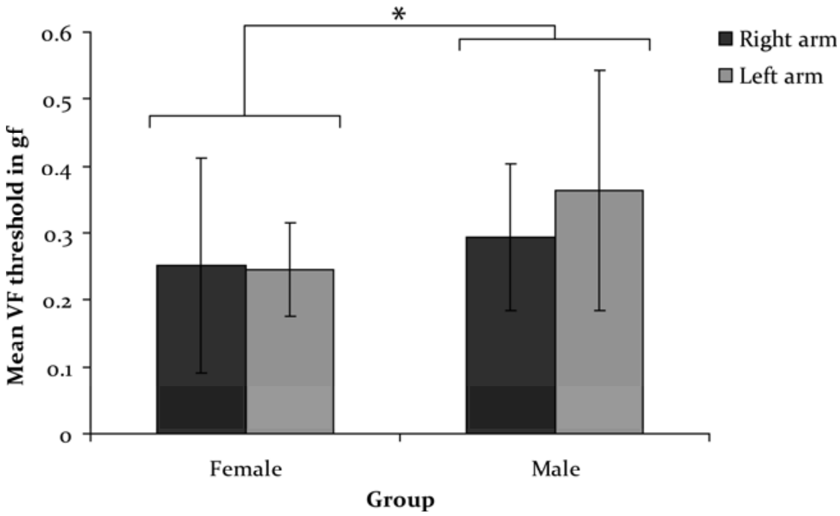


Figure 4. Results from the VF task by group and condition, showing a main effect for gender significant at the * p<.01 level. Error bars depict the SD.

4. Discussion

The current experiment shows that in a relatively easy way metric aspects of mental body representations can be assessed using the Tactile Estimation Task (TET). In about 10 minutes participants completed 15 trials in which they manually estimated the size between two tactile stimuli (50, 60 or 70 mm) that were simultaneously presented to their forearm with a calliper. The results show that the TET is a simple measure of metric aspects of the mental representation of the body in the brain. Moreover, it is unaffected by gender, the location on which the stimuli were presented (left arm vs right arm) and unaffected by the hand with which the distance estimations were made (left vs right hand).

Based on previous findings (e.g. Spitoni et al., 2010; Taylor-Clarke et al., 2004) we assumed that the TET taps into a higher order mental representation of the body. This is indeed what we observed as pressure detection and tactile size estimation did not correlate. These results are in accordance with previous studies showing that bodily illusions influence size judgments of touch to the skin, without affecting lower level somatosensory processing (e.g. Taylor-Clarke et al., 2004). Size judgments of two touches to the skin cannot be made without accessing metric information regarding the size of the body part being touched. Such information is not conveyed by skin receptors (Spitoni et al., 2010). Therefore, what was felt on the skin needs to be integrated with a higher order metric representation of body part size, which is stored in a mental body representation.

Interestingly, we did not find any differences in size estimation between the different conditions of the TET. Apparently, size estimations are not affected by the location of presentation of stimuli (left or right arm) and the hand with which the estimation is made (left or right hand). Also, we did not find any gender differences in the TET. Weinstein (1968) showed that on low level measures of tactile perception, in which a mental representation of the body is supposedly not accessed (Spitoni et al., 2010), such as point localization, two point discrimination, and pressure sensitivity, differences between the left and right side of the body can be identified, as well as gender differences. When judging the size of tactile stimuli, as in the TET, such differences are thus absent, which indicates that this distorted input from SI is rescaled according to a higher order mental representation of the size of the body, which may be assumed to be similar for the left and right side of the body in healthy participants.

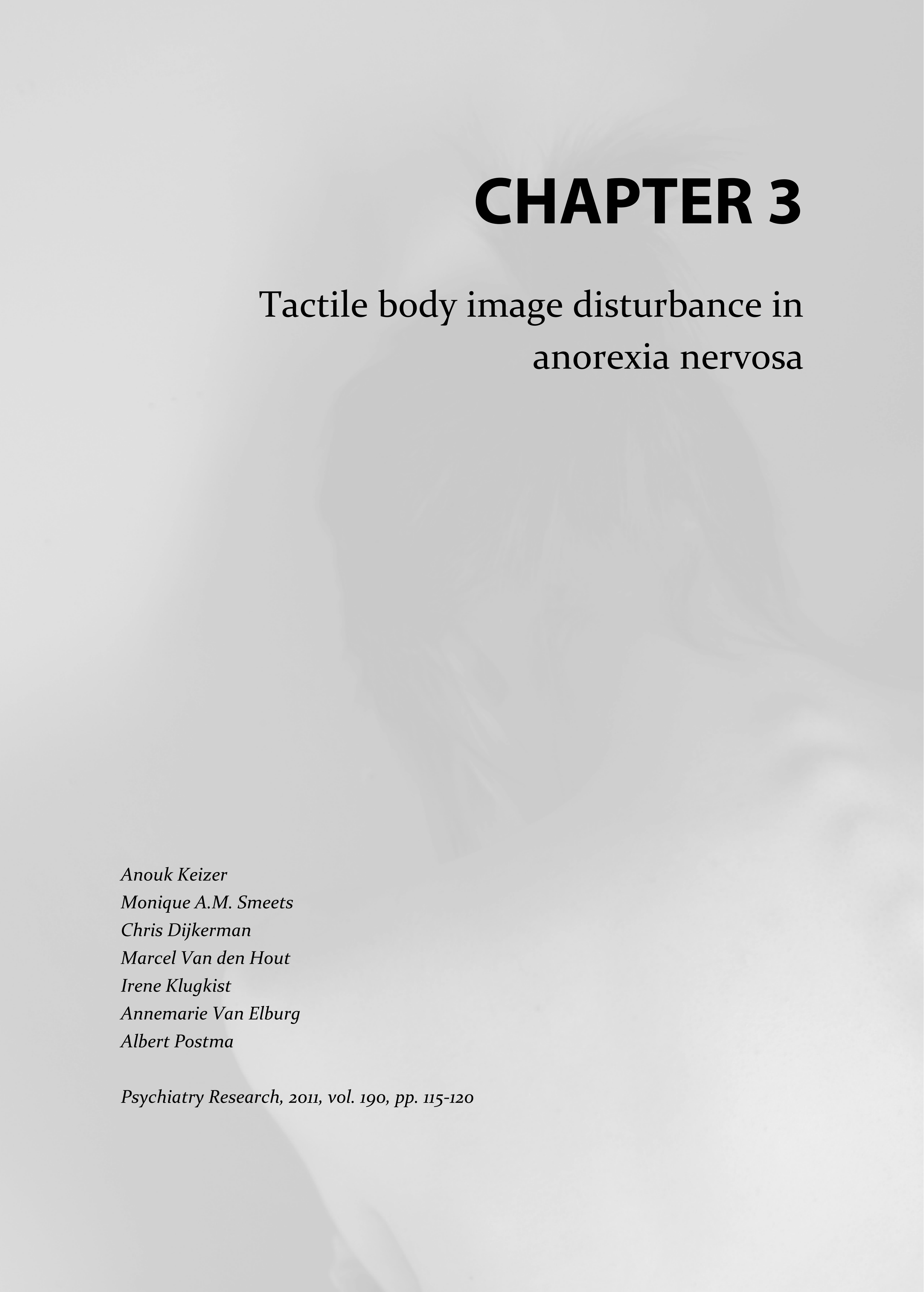
Further, the results showed a difference between verbal and manual size estimation, with manual size estimations being more accurate. More importantly, there was no correlation between manual and verbal size estimates, suggesting that manually estimating the distance between two stimuli is dependent upon different processes than verbally estimating it. Thus, a manual response is preferred and cannot be directly replaced by asking participants to give a verbal response of what they felt on their skin.

The TET has a number of advantages over other tactile tasks generally used to assess mental body representation. In these tasks participants commonly receive two identical tactile stimuli on two body parts, and are asked to indicate which stimulus felt largest (e.g. Spitoni et al., 2010). First, the TET does not require participants to memorize the first stimulus and compare the remembered size of the stimulus with the second one. Second, the TET enables researchers to focus on possible disturbances in a single body part, or compare the extent of metric body representation disturbances over multiple body parts. For example, recently the TET was already administered in a group of AN patients (Keizer et al., 2011; Keizer et al., 2012). Participants received tactile stimuli on the right side of their forearm and right side of the abdomen. The results indicated that AN patients overestimated the size of tactile stimuli compared controls and the actual presented distance (Keizer et al., 2011; Keizer et al., 2012). Importantly, the difference in size estimation between AN patients and controls was largest for stimuli presented to the abdomen, a body part AN patients typically worry about, compared to stimuli presented to the arm (Keizer et al., 2012). Further, AN patients' size estimations in the TET were not predicted by their ability to detect touch as measured with the VF task (Keizer et al., 2012).

Another advantage of the TET that increases its flexibility in terms of adapting it to certain clinical populations is that for patients who are easily worn out physically or cognitively, the TET could be shortened by including only two stimuli distances. Anecdotal reports from participants in the current study indicated that they were not aware of the amount of different stimuli being used in the task. Most participants expected a larger amount than three different distances. This suggests that when the TET is shortened, the risk of participants categorizing the stimuli as e.g. "small" and "large" is relatively small. Especially when the experimenters explain before completing the TET that there is a variety of different stimuli that will be presented. The absence of differences between estimating stimuli distance on the right and left arm, and using the right or left hand gives researchers and clinicians the opportunity to choose the most convenient method tailored to their patient group. It is advantageous that we identified no gender differences, as recruiting suitable patients can be difficult when one aims to use the method in scientific research. Being able to include both males and females in the patient group increases statistical power.

A limitation of the current study is that TET requires the use of a computer or laptop and touchpad on which participants estimate the distances. However, size judgments might also be made on a sheet of paper, on which the experimenter marks the middle of the thumb and index finger, to determine the size estimation with a ruler. Also, the population that was tested here was not diverse and large enough to provide good clinical norm data against which clinical scores can be compared. However, with this paper we hope to accelerate research within this area, increase awareness of body representation disorders and facilitate using this metric in the clinic field.

Taken together, we show here that the TET is a simple and elegant way to assess metric mental body representations. The results suggest that healthy individuals are able to successfully rescale distorted tactile input based on a mental body representation. Further, the TET is a promising task for researchers and clinicians working with patient populations. It is not only short and easy to administer, it is also possible to adapt it in such a way that it is most convenient for the patients, and most relevant for the researchers and clinicians.



CHAPTER 3

Tactile body image disturbance in anorexia nervosa

Anouk Keizer
Monique A.M. Smeets
Chris Dijkerman
Marcel Van den Hout
Irene Klugkist
Annemarie Van Elburg
Albert Postma

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Abstract

Body image disturbances are central to anorexia nervosa (AN). Previous studies have focused mainly on attitudinal and visual aspects. Studies on somatosensory aspects thus far have been scarce. We therefore investigated whether AN patients and controls differed in tactile perception, and how this *tactile body image* related to visual body image and body dissatisfaction. The Tactile Estimation Task measured tactile body image: Two tactile stimuli were applied to forearm and abdomen, and, while blindfolded, participants estimated the distance between the two tactile stimuli between their thumb and index finger. The Distance Comparison Task measured visual body image. Compared to controls (n=25), AN patients (n=20) not only visualized their body less accurate, they also overestimated distances between tactile stimuli on both the arm and abdomen, which might reflect a disturbance in both visual and tactile body image. High levels of body dissatisfaction were related to more severe inaccuracies in the visual mental image of the body, and overestimation of tactile distances. Our results imply that body image disturbances in AN are more widespread than previously assumed as they do not only affect visual mental imagery, but also extend to disturbances in somatosensory aspects of body image.

1. Introduction

The disturbed experience of body weight and shape is a central diagnostic criterion of anorexia nervosa (AN, APA, 2000): Despite their emaciated appearance, AN patients experience their body as too fat. This disturbance in body image is considered to be a key factor in the development, maintenance and relapse of AN (Keel et al., 2005; Killen et al., 1996; Stice, 2002; Stice and Shaw, 2002). In addition body image problems are often found to persist after otherwise successful treatment (Carter et al., 2004; Exterkate et al., 2009). Literature on body image in AN has focused mainly on attitudinal (e.g. body dissatisfaction) and visual aspects of body image (Farrell et al., 2005; Garner, 2002; Skrzypek et al., 2001; Smeets, 1997; Smeets et al., 1997), which were found to correlate (Benninghoven et al., 2007; Cash and Deagle, 1997; Sunday et al., 1992), implying a mutual relationship. Cash and Deagle (1997) showed that AN patients are more dissatisfied with their body than controls (d=1.10) and that this disturbance in body attitudes is much larger than that of the visual body image disturbance (d=0.64).

Even though body image is regarded as a multifaceted concept including cognitive/affective and perceptual aspects of how the own body is experienced (Cash, 2002; Cash and Pruzinksy, 2002), surprisingly little is known about somatosensory aspects of body image in AN. A few studies have however shown that AN patients have a decreased interoceptive awareness and sensitivity. AN patients do not only demonstrate a decreased ability to identify and discriminate between visceral sensations related to hunger and satiety (Fassino et al., 2002; Matsumoto et al., 2006; Pollatos et al., 2008), they also have difficulty to recognize physiological stress symptoms such as an increased heart rate (Miller et al., 2003; Zonnevylle-Bender et al., 2005). These findings imply that AN patients have a deficit in recognizing bodily signals, which may extend to deficits in somatosensory perception as well. Therefore, the main aim of the current study was to investigate whether AN patients suffer a disturbance in *tactile body image*.

Previous research suggests that two forms of touch can be distinguished in the brain, primary tactile perception (such as an external object pressing on the skin) and secondary tactile perception (including metric/spatial information and requiring rescaling; Spitoni et al., 2010). We are especially interested in secondary tactile perception, because extracting metric information from the skin surface involves additional computational processing stages over perceiving mere contact to the skin (Dijkerman and de Haan, 2007; Spitoni et al., 2010). It is thought that during these additional processing stages touched locations on the skin are linked to a mental body representation (Spitoni et al., 2010).

The concept mental body representation refers to the multiple abstract perceptual representations of the body in the brain that store information about the shape and size of body parts, their position in space and the integration of the parts into a structural whole (Dijkerman and de Haan, 2007; Gallagher, 2005; Paillard, 1999; Serino and Haggard, 2010). It has been suggested that these mental body representations are constructed from and reciprocally influenced by input from various senses such as vision and touch (Serino and Haggard, 2010). Moreover, certain aspects of body representations may not only be influenced by bottom-up sensory input, but also by top-down cognitive, semantic and affective representations: When perceiving the body or sensations on the skin, top-down information is used (de Vignemont, 2010; Dijkerman and de Haan, 2007; Gallagher, 2005; Paillard, 1999).

Touch is necessarily perceived in reference to the own body. Since somatosensory afferents do not provide bottom-up information about the size of a body part (Serino and Haggard, 2010), it is crucial to tap into other sources of information, providing top-down input, such as vision (Taylor-Clarke et al., 2004) or perhaps mental imagery, in order to make size estimations of tactile objects. In addition, top-down processes related to for example body dissatisfaction could influence and distort mental representations, making it plausible that AN patients estimate the size of external tactile stimuli in reference to a disturbed mental representation of the body. In healthy individuals it was indeed shown that after experimentally inducing a disturbed experience of the body, tactile perception of distances was altered (de Vignemont et al., 2005; Taylor-Clarke et al., 2004).

Previous work has already demonstrated that top-down processes related to body attitudes can lead to marked visual body image disturbances. For example, Smeets and Kosslyn (2001) found that AN patients' visual body image disturbance results from body size distortions in memory rather than perception (see also Kosslyn, 1987; Smeets et al., 1999). While AN patients' visual size discrimination is undisturbed (Garfinkel et al., 1978; Smeets et al., 1999), thinking about the self as fat (i.e. high body dissatisfaction) may cause size distortions of the visual mental body image. One proposed mechanism held that "thinking fat" acitvated prototypical images of fat somatotypes which interfere with the construction of a visual mental image of the body and distort it in the direction of fatness (Mohr et al., 2007; Smeets and Kosslyn, 2001). Following this line of reasoning, we believe an investigation of body size representations within multiple modalities in AN is warranted. Therefore we specifically investigated whether AN patients demonstrate a disturbance in tactile aspects of body image, and explored how this disturbance related to body dissatisfaction and visual aspects of body image.

2. Methods

2.1. Participants

The present research was approved by the local medical ethical committees of the involved institutions. Forty-five Dutch females participated: 20 AN patients and 25 healthy controls. All participants were over 18 years of age, free from medication that could influence psychomotor speed (e.g. due to sedative effects, drowsiness, or psychomotor impairment), and scar tissue (e.g. due to self-injuring behaviour, a surgery, or an accident) or skin problems (e.g. a rash due to allergies) on their forearms and abdomen. Participants received a monetary reward for a 90 minutes session.

AN patients were recruited from an eating disorder clinic outpatient population. All patients received treatment as usual and were diagnosed with AN (n=15) or the AN subtype of eating disorder not otherwise specified (EDNOS, n=5) by administering the Eating Disorder Examination (EDE; Fairburn and Cooper, 1993) and a psychiatric interview. We included both AN patients and AN subtype EDNOS patients who no longer or had never fulfilled the AN Body Mass Index (BMI) and/or amenorrhea criterion, as symptoms are similar although less severe in EDNOS (Williamson et al., 2002). Mean disease duration was 8.4 months (SD=6.5): Note that patients may have previously received treatment elsewhere. Healthy controls were recruited from a student population. Based on their measured weight and height, all controls had a healthy BMI (18.5 to 25) and the presence of an eating disorder was excluded by administering the Eating Disorder Diagnostic Scale (EDDS; Stice et al., 2004). Mean age was 22.30 years (SD=3.01) for AN patients and 21.32 years (SD=2.19) for controls, $t(43)=1.26$, $p=.213$. Mean BMI was 18.54 (SD=2.03) for AN patients; and 21.43 (SD=1.77) for controls, $t(43)=-5.11$, $p<.001$. Note that the mean BMI in the AN group is relatively high as the AN group consists of both AN patients and EDNOS patients.

2.2. Instruments and procedures

2.2.1. Body dissatisfaction

The Dutch translation of the Body Shape Questionnaire (BSQ; Cooper et al., 1987) assessed body dissatisfaction. This widely-used, 34-item, self-report questionnaire with an internal consistency of α=0.97 (Pook et al., 2008) assessed concerns regarding body shape during the last four weeks on a 6-point Likert-scale (e.g. *"Did you avoid social events (such as parties) because you felt bad about your body size?"*). Cronbach's *α* in the current sample was 0.99.

2.2.2. Tactile body image

The Tactile Estimation Task (TET; adapted version based on Anema et al., 2008; de Vignemont et al., 2005; Taylor-Clarke et al., 2004) measured tactile body image. While participants were blindfolded, the experimenter pressed the two pointers of a caliper simultaneously and lightly on the skin. The distance between the two pointers was set at 50, 60, and 70 mm, with each distance being presented seven times in a random order on the right side of the body. Two body parts were tested in a counterbalanced order, the centre of the right forearm (insensitive body area, see Figure 1A) and the abdomen in the area below the belly button (sensitive body area, see Figure 1B). We distinguished between sensitive and insensitive body areas to investigate whether body image disturbances in AN occur for any body part, or only for those subject to the highest level of body dissatisfaction. During the task, participants estimated the distance between the two tactile stimuli by varying the separation between their right thumb and index finger. The experimenter measured this estimation with the caliper (see Figure 1C).

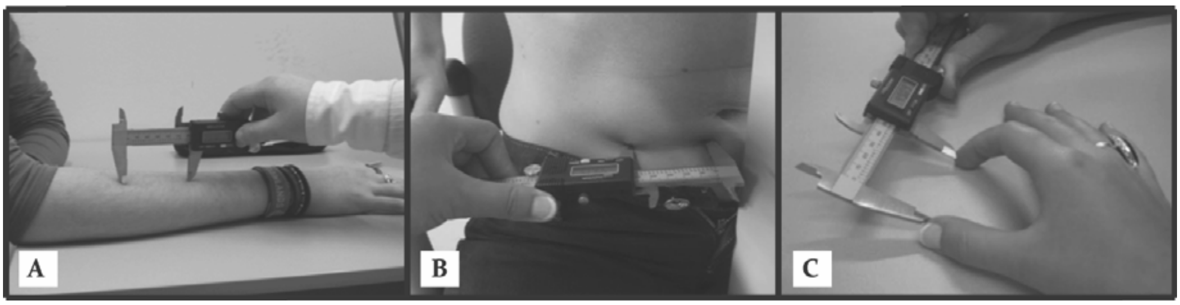

Figure 1. Example trial of the Tactile Estimation Task. Panel A depicts tactile stimuli being applied to the arm; panel B depicts tactile stimuli being applied to the abdomen; panel C depicts the experimenter measuring the distance estimation made by the participant.

2.2.3. Visual body image

The Distance Comparison Task (DCT; Denis and Zimmer, 1992; Noordzij and Postma, 2005; Smeets et al., 2009) is not a classical body size estimation task in which participants estimate the size of their body by manipulating a distorted visual stimulus depicting their own body until it is perceived as matching own size. The disadvantage of such a task would be that presenting a visual image will influence the person's own visual mental image, preventing an unbiased assessment of that image (see e.g. Kosslyn, 1987; Smeets et al., 1999; Smeets and Kosslyn, 2001). The DCT was designed to spontaneously activate the visual body image (i.e. a visual image *must* be constructed in order to conduct the task and derive size estimates) without presenting a visual depiction of the body. The DCT is based on the so-called "image-scanning paradigm" (see Smeets et al., 2009) in which a visual mental image of the own body is constructed and used when judging size differences between word-pairs. In each trial two word-pairs were presented, both representing a horizontal distance on the body. Each word-pair consisted of two identical body parts, representing the left and right side of the body, e.g. ear-ear and hip-hip. Participants were subsequently asked to indicate whether the last presented word-pair reflected a larger or smaller distance on their own body than the first presented word-pair. For example, participants had to indicate whether the horizontal distance between their left and right hip was larger or smaller than the horizontal distance between their left and right ear, see Figure 2.

We demonstrated an inverse relation between reaction time (RT) and the absolute distance between the word-pair combinations confirming that a visual mental image was generated and used during the task. For example, the distance difference between ear-ear and hip-hip is large, as the ears are close to each other, while the hips are not, resulting in small RTs. Word-pairs consisted of the body parts waist, hips, and thighs (sensitive body parts), and ears, shoulders, armpits, elbows, and knees (insensitive body parts). A total of 28 word-pair combinations (e.g. a trial consisting of shoulder-shoulder paired with hip-hip) were presented twice in two cycles in a counterbalanced order, word-pair combinations within the cycles were randomized. Presentation times of the word-pairs were based on Smeets and colleagues (2009).

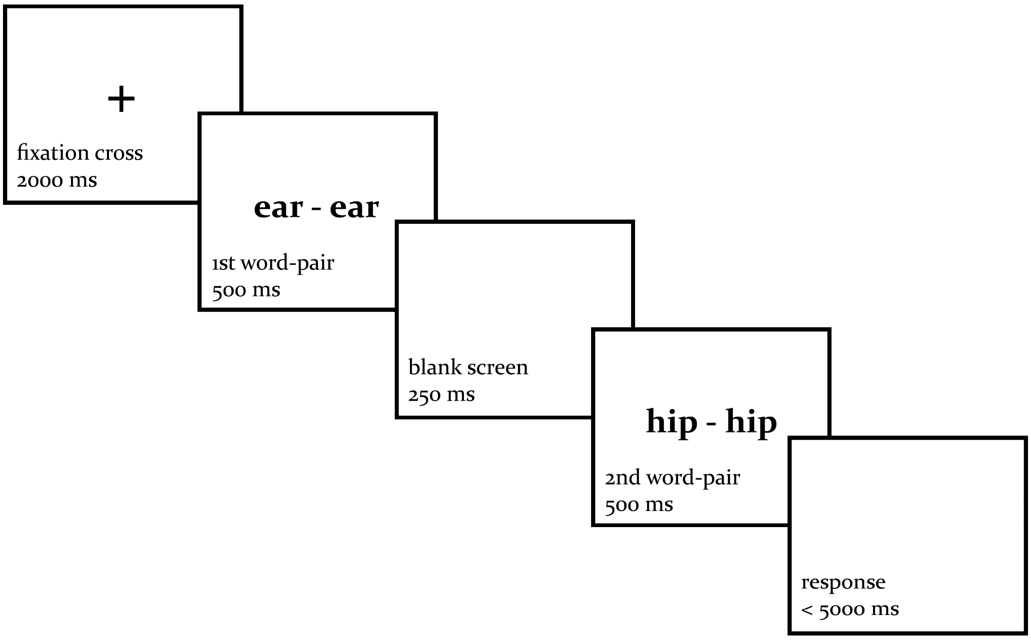

Figure 2. Example trial of the Distance Comparison Task.

3. Results

3.1. Tactile body image

The effect of distance between the two simultaneously applied tactile stimuli on the index finger-thumb separation was not relevant to the aims of the current study and did not interact with group, $F(2,42)=2.48$, $p=.096$, therefore responses on the three distances were averaged and the analyses were proceeded without stimuli distance as a variable. Mean distance estimation in the TET was 80.60 mm (SD=13.18) for AN patients and 49.88 mm (SD=12.47) for controls. A mixed repeated measures ANOVA showed a significant main effect of group, $F(1,43)=64.16$, $p<.001$, $d=2.47$, indicating that AN patients made larger distances estimations than controls (see Figure 3). There was no main effect of body part, $F(1,43)=1.64$, $p=.208$, nor an interaction between body part and group, $F(1,43)=1.76$, $p=.192$. Bonferroni-corrected one sample t-tests, demonstrated significant deviation from the mean applied distance of 60 mm in the AN group, $t(19)=6.99$, $p<.001$, $d=1.62$ and control group, $t(24)=-4.06$, $p<.001$, $d=0.86$ but in opposite directions (see Figure 3). The continuous variable BMI was not included as a covariate in the model as it showed no main effect, $F(1,42)=1.49$, $p=.229$, nor an interaction with body part, $F(1,42)=2.27$, $p=.140$ or group, $F<1$, while the main effect of group remained significant, $F(1,42)=31.41$, $p<.001$.

Taken together, AN patients showed a disturbance in tactile distance estimation: Regardless of the sensitivity of the body part they overestimated the distance between two tactile stimuli relative to controls. While AN patients overestimated tactile distances with regard to the actual applied distance, controls underestimated tactile distances.

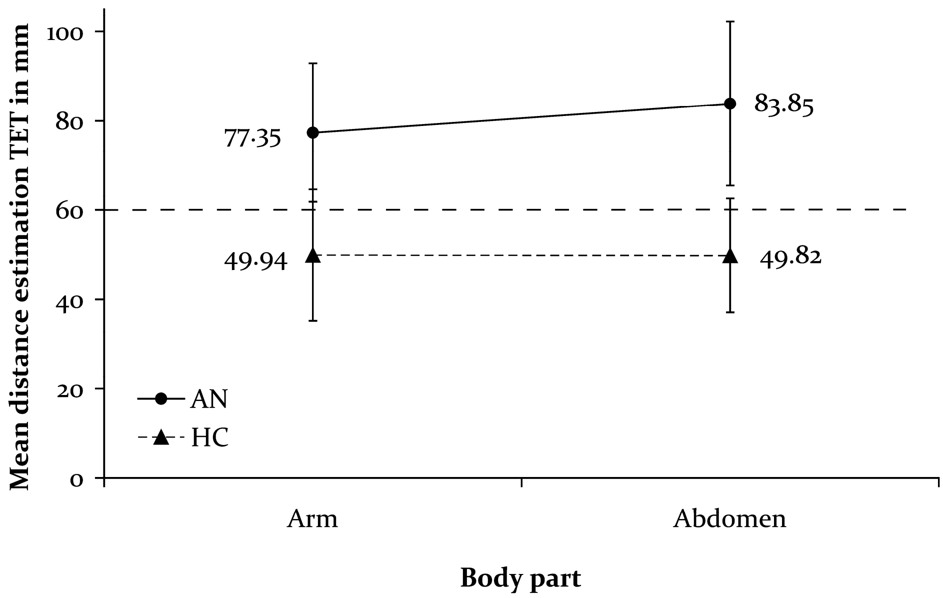

Figure 3. Main effect of group, indicating that compared to controls, Anorexia Nervosa (AN) patients overestimated tactile distances in the Tactile Estimation Task (TET). In both groups distance estimations deviated from the actual applied distance of 60 mm. Vertical lines depict SD. The dashed line at 60 mm represents an accurate distance estimation.

3.2. Visual body image

As individuals differ in actual body size, the distance differences to be judged in the DCT varied as well per participant. We took this into consideration by analyzing the data with Multilevel (ML) regression analyses (Hox, 2002) in MlwiN 2.0 (Goldstein et al., 1998). Following Smeets and colleagues (2009) measurements associated with RTs smaller than 200 ms and longer than 4000 ms, and measurements associated with distance differences larger than 25 cm were removed from the dataset, resulting in 2126 datapoints.

Mean *accuracy* score on the DCT was 66.88% (SD=10.91) for AN patients and 74.73% (SD=15.20) for controls, d=0.59. The final logistic ML model for accuracy included the significant predictors distance difference, $B_{distance\_difference}$=0.09, p<.001, and group, B_{group}=0.45, p=.011. Sensitivity of the word-pair and BMI were removed from the model as they did not significantly predict accuracy, $B_{sensitivity}$=-0.06, p=.341; B_{BMI}=0.05, p=.213.

Mean *RT* in the DCT was 1683.91 ms (SD=534.95) for AN patients and 1665.02 ms (SD=673.72) for controls. The final ML model for RT included the significant predictor distance difference, $B_{distance\_difference}$=-17.56, p<.001. Sensitivity, group and BMI were not included in the model as they did not significantly predict RT, $B_{sensitivity}$=-52.56, p=.081; B_{group}=-6.07, p=.382; B_{BMI}=0.76, p=.494.

Taken together, in both the AN and control group, larger distance differences were easier to evaluate than smaller distances differences. More importantly, AN patients appeared to have constructed an unrealistic visual mental image of their body compared to controls, as AN patients were less likely to correctly indicate which of two word-pairs represented the largest horizontal distance on their body.

3.3. Relation between body dissatisfaction and tactile body image

AN patients showed significantly higher levels of body dissatisfaction (BSQ) than controls, t(43)=8.70, p<.001, d=2.48, with a total BSQ score of 95.85 (SD=39.46) for AN patients and 23.16 (SD=12.60) for controls. Separate linear regression analyses showed that BSQ score was significantly related to accuracy in the DCT, β=-0.41, p=.005, R^2=.17, and TET distance estimation, β=0.66, p<.001, R^2=.44. After controlling for BSQ score, there was no significant relation between TET distance estimation and DCT accuracy, β=-0.05, p=.692. BMI was not included in the models as it did not correlate with DCT accuracy score, r=.27, p=.069, and despite the significant correlation with TET distance estimation, r=-.57, p<.001, it did not improve the model significantly, β_{BMI}=-0.11, p=0.432; β_{TET}=0.60, p<.001, R^2=.45, $R^2\Delta$=.01. Taken together, as BSQ scores increased, the size of TET distance estimates increased accordingly, while accuracy on the DCT decreased, implying that severity of body dissatisfaction was related to severity of both visual and tactile aspects of body image disturbances.

4. Discussion

In the present experiment we investigated body image disturbances in AN patients at three levels. AN patients did not only demonstrate higher levels of body dissatisfaction and an inappropriate visual mental image of their body than controls, they also overestimated the size of tactile distances. There was no difference in magnitude of overestimation between sensitive and insensitive body parts in both the TET and DCT, implying a more generalized tendency of AN patients to conceptualize their body as inappropriate. We further found that high levels of body dissatisfaction were related to more severe tactile and visual body image disturbances.

One explanation for this finding holds that body image disturbances in AN in the tactile and visual modality result from top-down influences of body dissatisfaction on the mental body representations necessary in tactile size estimation (de Vignemont et al., 2005; Serino and Haggard, 2010; Taylor-Clarke et al., 2004) and visual imagery (e.g. Lupyan et al., 2010). The high levels of body dissatisfaction encountered in AN patients may influence mental body representations, which in turn could distort sizes estimates related to the own body in the visual and tactile domain.

This line of reasoning is supported by behavioural (e.g. Lupyan et al., 2010; Smeets and Kosslyn, 2001; Taylor-Clarke et al., 2004) and neuroimaging research (e.g. van Kuyck et al., 2009). For example, behavioural studies showed that in healthy individuals size perception of external objects varied depending on the mental representation of the body part it was touching, despite the fact that across different locations on the body afferent input was constant (de Vignemont et al., 2005; Taylor-Clarke et al., 2004). Further, neuroimaging research implies that AN patients are more emotionally involved when processing body- and disease-related stimuli (e.g. Uher et al., 2005; van Kuyck et al., 2009): Increased activity was found in the anterior cingulate cortex (e.g. Friederich et al., 2010; Wagner et al., 2003) and amygdala (e.g. Miyake et al., 2010), while decreased activity and gray matter density was found in brain areas important in visual body processing (e.g. extrastriate body area; Suchan et al., 2010; Uher et al., 2003) and perceiving body size and shape (e.g. posterior parietal cortex; Goethals et al., 2007; Mohr et al., 2010; van Kuyck et al., 2009). These findings imply that indeed top-down information in body processing is more dominant in AN patients compared to controls. Interestingly, controls showed relative underestimation of tactile distances. This finding echoes earlier studies on tactile distance perception in individuals without an eating disorder (Anema et al., 2008; Taylor-Clarke et al., 2004). Underestimation by healthy controls characterizes performance on visual body image tasks as well (e.g. Nederkoorn et al., 2008; Smeets and Kosslyn, 2001). Thus, body dissatisfaction and body size representation seem inversely related. Actual BMI did not influence the results from either the TET or DCT, which makes it unlikely that the fluctuating body mass of AN patients due to treatment has influenced the findings (see also McCabe et al., 2006; Mussap et al., 2008).

An alternative explanation for the current findings is that higher level mental representations of size have become distorted via *a bottom-up* route. However, there are several findings that challenge this interpretation. First, it is unlikely that the *visual* body image disturbance is the result of an elementary perceptual deficit, as it has been found that AN patients and controls do not differ in visual object-size estimation (e.g. Cash and Deagle, 1997; Garfinkel et al., 1978). In addition research indicated that perceptual sensitivity for changes in visual stimuli related to both their own body and the body of others is equal for AN patients and controls (see e.g. Smeets et al., 1999). These findings suggest that although AN patients overestimate their body size in visual body image tasks compared to controls, this is unlikely to result from bottom-up differences in visual processing. In addition, overestimation of *tactile* distances by AN patients is unlikely to have resulted from a perceptual disturbance at for example receptor level, as previous research indicated that AN patients and controls do not differ in vibration thresholds (Pauls et al., 1991) and that Bulimia Nervosa (BN) patients and controls do not differ in pressure thresholds measured with Von Frey filaments (Faris et al., 1992).

On the other hand: even if unlikely, a bottom up explanation for the phenomena demonstrated in this paper cannot be completely ruled out. For example, studies including healthy subjects showed that after reducing afferent transmission due to anesthesia of the thumb, this resulted in an increased perception of the size of the thumb (Gandevia and Phegan, 1999). Therefore, future studies should include assessments of tactile sensation and discrimination, such as the two-point threshold, to fully address this issue. Related to this, based on the finding of nonselective overestimation of distance on both the arm and the abdomen, an alternative explanation of these findings could be that AN patients generally overestimate size or distance. Previous studies have shown that AN patients and controls do not differ making visual size estimates of neutral objects (e.g. Cash and Deagle, 1997; Garfinkel et al., 1978). We expect similar results for the tactile domain. However, to completely rule out this alternative explanation, research is needed in which participants make size estimations of objects using a different type of somatosensory input. For example, future studies could focus on haptic size estimation, by including a task in which participants estimate the size of a wooden block using active tactile exploration of the object with the fingers.

Finally, in previous research using visual body size estimation tasks in which participants estimated the width of their body or specific body parts, demand characteristics have been proposed as confounding factors (Proctor and Morley, 1986). We deem an explanation in terms of demand characteristics unlikely here. With respect to the visual task, the DCT was designed specifically to prevent influences of demand effects (see also Smeets et al., 2009). The DCT is a complex RT task requiring a quick response. Even if the participant can guess the hypothesis, it is hard to come up with a strategy at the level of individual trials aimed at confirming that hypothesis. Nonetheless, AN patients' visual mental image of the body was inappropriate compared to that of controls. With respect to the tactile task, in the TET both instructions and stimuli were kept neutral. Participants were not asked to estimate the size of their body or a certain body part, they merely had to indicate the size of tactile stimuli applied to their skin. Participants were specifically instructed to estimate as accurately as possible the size of an external stimulus based on what they felt on their skin. In view of this, it is unlikely that participants *consciously* and strategically altered their distance estimations in order to confirm or disconfirm the hypothesis. Taken together, we believe it is more likely that overestimation of tactile distance on the skin by AN patients reflects top-down processes, e.g. in the way of activated attitudes about the body influencing size estimates, rather than conscious decisions to please to experimenter.

It should be noted that the current results are correlational, and that neither body dissatisfaction nor body image was experimentally manipulated. The disturbances found in the AN group were already present at the time of testing, making it impossible to draw conclusions regarding the direct cause of body representation disturbances in AN. It is likely that a reciprocal causal relationship exists between body dissatisfaction and body image. If this is the case, the implication would be that body size representation disturbances can be improved by interventions at either the level of cognition and affect as well as visual or tactile body image levels. Future studies could focus on both directions. For example by decreasing body dissatisfaction in cognitive behaviour therapy (CBT) or by directly influencing tactile and visual body image in for example a training program (Salemink, 2008) in which accurate feedback reduces the tactile and visual body image disturbance. Would such training programs prove to be successful in reducing body image disturbances, they could be useful in treatment as well. Previous studies emphasized the importance of targeting body image disturbances in the treatment of eating disorders in order to attain full recovery without residual body image problems (e.g. Bardone-Cone et al., 2010; Keel et al., 2005; Nico et al., 2010). Our findings reaffirm this importance for AN patients specifically as it appears that body image disturbance are more severe than previously assumed: They do not limit themselves to body dissatisfaction and unrealistic visual mental images of the body, but extend to deficiencies in somatosensory perception.

In summary, we found that AN patients create an inappropriate visual mental image of their body. More interestingly, AN patients also overestimate tactile distances. This may indicate that body image disturbances in AN extend from visual to somatosensory perception. Both the visual and tactile body image disturbances were related to body dissatisfaction, which, supported by findings from behavioural and neuroimaging studies, argues for top-down influences of body dissatisfaction on the visual mental image of the own body and the perception of tactile distances.

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CHAPTER 4

Aberrant somatosensory perception in anorexia nervosa

Anouk Keizer
Monique A.M. Smeets
Chris Dijkerman
Annemarie van Elburg
Albert Postma

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Abstract
Anorexia Nervosa (AN) patients have a disturbed experience of body size and shape. Previously it has been shown that these body representation disturbances extend to enlarged perception of tactile distances. Here we investigated whether misperception of tactile size could be related to inaccurate elementary somatosensory perception. Compared to controls (n=28), AN patients (n=25) overestimated tactile size, this effect was strongest for the abdomen. Elementary tactile perception deviated in AN as well: Patients had a lower threshold for detecting pressure on their abdomen, and a higher threshold for two point discrimination on both the arm and abdomen. Regression results implied that group membership (i.e. AN vs control) predicted tactile size estimation on the arm. Both group membership and two point discrimination predicted tactile size estimation on the abdomen. Our results show that AN patients have a disturbance in the metric properties of the mental representation of their body as they overestimate the size of tactile stimuli compared to controls. Interestingly, AN patients and controls differ in elementary somatosensory perception as well. However, this can not solely explain misperception of tactile distances, suggesting that both bottom-up and top-down processes are involved.

1. Introduction

Central symptoms of anorexia nervosa (AN) are denial of low body weight, an intense fear of gaining weight or becoming fat while being underweight, and an unrealistically fat experience of the own body (APA, 2000). These symptoms have been linked to the development and maintenance of AN (Killen et al., 1996; Stice, 2002; Stice and Shaw, 2002), unsuccessful treatment (Carter et al., 2004; Exterkate et al., 2009) and relapse (Stice and Shaw, 2002). Further, the disturbed experience of the body implies that AN patients have an inaccurate internal representation and experience of the shape and size of their body. More specifically, metric aspects of the mental representation of their body could be disturbed (see e.g. Guardia et al., 2010; Nico et al., 2010 on how body representation disturbances may affect body scaled action in AN).

In the literature often a distinction between different body representations is made. Particularly, the idea of two separate representations, body image, which is mainly cognitive perceptual, and body schema, subserving sensorimotor action, is dominant (e.g. Gallagher, 2005). However, there is no real consensus on how many separate body presentations can be identified, and what exactly each representation would entail (for a review see de Vignemont, 2010). Therefore, in the current article we adopt the more neutral term mental body representation.

Mental body representations are believed to store information on body part size and shape, the position of the body parts in space, and the integration of multiple parts into a whole (Dijkerman and de Haan, 2007; Gallagher, 2005; Paillard, 1999; Serino and Haggard, 2010). They are invoked in both perception and action, and are crucial in a wide variety of behaviours, such as imagining how the own body looks, reaching towards objects (Dijkerman and de Haan, 2007; Kammers, 2009; Serino and Haggard, 2010), and spatial orientation constancy (Funk et al., 2010). Spatial orientation constancy has already been found to be impaired in AN patients (Grunwald et al., 2002; Guardia et al., 2012b). It is suggested that different body representations play different roles, and that encoding of bodily information in the brain depends on how bodily information is used in a given situation (de Vignemont, 2010).

Mental body representation in the context of metric characteristics of the body refers to an abstract, multimodal representation of the own body (Dijkerman and de Haan, 2007). Both bottom-up sensory input, such as vision and touch, and top-down cognitive input, for example related to semantic and affective information, are supposedly used to construct the mental body representation (de Vignemont, 2010; Serino and Haggard, 2010). Although the information used to construct a (metric) mental body representation comes in various formats and frames of reference, the brain selects and integrates relevant information for the given context or task (see e.g. de Vignemont, 2010).

Previous research on body representation disturbances in AN has mainly focused on aberrant visual images of the body (e.g. Cash and Deagle, 1997). These studies have shown that AN patients overestimate their body size in visual and visual imagery tasks (e.g. Cash and Deagle, 1997; Farrell et al., 2005; Keizer et al., 2011; Skrzypek et al., 2001; Smeets, 1997). It has been suggested that conceptual information can influence and distort visual (mental) processing (Kosslyn, 1987; Lupyan et al., 2010). In the context of AN, this could imply that inaccurate metric information regarding the body is retrieved from memory when creating a visual mental image of the body, possibly due to inappropriate concepts or beliefs (i.e. "I am fat"; Mohr et al., 2007; Smeets and Kosslyn, 2001). In other words the mental representation of the body in AN patients does not resemble their actual body size, consequently impairing size judgments related to the body.

Given the multimodal character of body representations (de Vignemont, 2010; Serino and Haggard, 2010), it is possible that disturbances in size judgments in AN patients are not limited to the visual modality, but extend to the tactile modality. Surprisingly, hardly any research has been conducted on somatosensory aspects of body representation in AN. Studies of healthy participants showed that a mental body representation related to metric properties of body(part) size is accessed when participants were asked to make judgments of the size of external stimuli touching the skin surface (de Vignemont, 2010; Spitoni et al., 2010). Since skin receptors do not directly convey information regarding metric characteristics of body parts (Serino and Haggard, 2010), information about what is felt on the skin has to be compared to, and integrated with, a stored higher order representation of body part size, which is mainly based on visual input (de Vignemont, 2010; Spitoni et al., 2010).

In a recent study, we investigated tactile size perception in AN by asking blindfolded participants to estimate the distance between two stimuli that were simultaneously pressed to their skin. Interestingly, we found that AN patients overestimated tactile stimuli size compared to controls (Keizer et al., 2011). These results seem to indicate that in AN tactile disturbances related to mental body representation can be identified as well. Similar to studies that show correlations between visual size estimation and body attitudes (Cash and Deagle, 1997), overestimation of tactile distances in AN patients correlated with negative attitudes and cognitions towards the body (Keizer et al., 2011).

Previous studies with healthy participants demonstrated that top-down processes, such as experimentally inducing a distorted experience of body size, influenced subsequent tactile size estimation (de Vignemont et al., 2005; Ehrsson et al., 2005b; Spitoni et al., 2010; Taylor-Clarke et al., 2004). Accordingly, top-down processes related to for example body dissatisfaction may play a causal role in overestimation of tactile body size in AN (see also Keizer et al., 2011). However, we cannot rule out that AN patients overestimated tactile distances due to more elementary deficits in somatosensory perception. Such bottom-up influences have been found in healthy participants as a result of for example anesthesia, where reduced afferent inputs resulted in an altered experience of the size of the thumb (Gandevia and Phegan, 1999).

It is clear that elementary and higher order somatosensory perception involve partially different neural processes. Elementary tactile perception such as the detection of pressure, mainly depends on processes early in the cortical hierarchy, in the contralateral primary somatosensory cortex , particularly Brodmann area 3B (Dijkerman and de Haan, 2007; Friedman et al., 2004). Neurons further away from the thalamic input in the primary somatosensory cortex, such as Brodmann area 1, display more complex response properties (Gardner, 1988). Somatosensory input is further processed in the secondary somatosensory area (SII) and in the posterior parietal cortex. Particularly the posterior parietal cortex has been related to higher order body representations (Berlucchi and Aglioti, 2010; Dijkerman and de Haan, 2007). Functional imaging studies show some overlap but also important differences in the neural processes underlying elementary somatosensory perception (pressure sensitivity) and higher order somatosensory perception (tactile distance judgments). Overlap occurs bilaterally in the anterior portion of the intraparietal sulcus, the inferior parietal lobule, the superior parietal lobule and the superior postcentral gyrus (Spitoni et al., 2010). For a higher order somatosensory task, activation in these areas was stronger than for an elementary task. In addition, for higher order somatosensory perception (such as tactile distance estimation), additional processing in the right parieto-occipito-temporal junction (POTJ) was identified, which suggests that the POTJ is involved in (processing of) the representation of actual body size required for tasks focusing on e.g. tactile distance estimation

(Spitoni et al., 2010). These higher order multimodal representations of the body may influence lower levels of somatosensory processing through top-down connections (Taylor-Clarke et al., 2004), which may allow body size scaling of tactile distances.

A few studies have been conducted on elementary tactile perception in eating disordered populations, and the results are somewhat contradictive. It has been found that bulimia nervosa (BN) patients have a lower pressure sensitivity than controls on both the finger tip and abdomen (Florin et al., 1988), but these results were not replicated (Faris et al., 1992). Further, elevated nociceptive thresholds for heat stimuli have been identified in BN patients (Faris et al., 1992; Lautenbacher et al., 1990; Papezova et al., 2005). Elevated pain thresholds have been found in AN patients as well (Papezova et al., 2005; Pauls et al., 1991), although not consistently (Lautenbacher et al., 1990).

In the current study we aimed to investigate whether AN patients would show deficits in elementary somatosensory perception. We included two measures of elementary tactile perception, one focusing on the detection of pressure provided by a single stimulus applied to the skin, and one focusing on spatial acuity, e.g. the minimum distance at which two stimuli applied simultaneously to the skin surface can be discriminated. In addition we employed the tactile size estimation task (Keizer et al., 2011). This task arguably operates a higher cognitive level (Spitoni et al., 2010). In order to make a size estimate it is necessary to first detect pressure on the skin at the site of stimulation, discriminate between the two pressure points, and then integrate what was felt on the skin with a mental representation of the distance between the pressure points on the skin. To investigate whether concerns about fatness of certain body parts might show specific differences between or within the patient and control group two body parts were tested in each tactile task: The abdomen, as this may be regarded as a high-concern body part (i.e. subject to high concerns of fatness in females), and the forearm, which may be seen as an neutral body part (i.e. not subject to high concerns of fatness).

2. Methods

2.1. Participants

The current study was approved by the local medical ethical committees of the involved institutions. In total 55 females participated. The patient group consisted of 25 patients (11 AN patients and 14 eating disorder not otherwise specified (EDNOS) patients), the healthy control group consisted of 28 undergraduate students. Participants received a monetary reward for a 60 minutes session.

All AN and EDNOS patients were recruited from an eating disorder clinic, where they received treatment as usual, ranging in frequency from daily to weekly sessions. Treatment as usual consisted of an integrated approach focusing on recovery of weight, eating pattern, and body attitudes, as well as normalizing family relations and social skills. None of the patients was hospitalized at the time of the study. Patients were diagnosed with AN or EDNOS by administering the Eating Disorder Examination (EDE; Fairburn and Cooper, 1993) and a psychiatric interview. As we recruited patients that all received treatment aimed at gaining weight, some patients with an initial AN diagnosis no longer fulfilled the weight and/or amenorrhea criterion for AN at the time of the study and their diagnosis changed from AN to EDNOS (APA, 2000). However, main eating and body image pathology persisted and it is suggested that EDNOS patients resemble AN patients although with less severe symptoms (Machado et al., 2007; Williamson et al., 2002). Previous studies also included both AN and EDNOS patients and reported no differences between the groups (e.g. Rodriguez-Cano et al., 2009). Indeed, AN and EDNOS patients did not differ on any of the tasks administered in the present study, therefore we did not differentiate in subsequent analyses between AN and EDNOS patients and will refer to this group as the patient group or AN patients.

All participants were above 18 years of age, right handed, and free from scar tissue on their right arm and right side of their abdomen. Mean age was 24.16 (SD=4.24) for the patient group and 22.54 (SD=2.52) for the control group, $t(51)=1.72$, $p=.092$. All controls had a healthy BMI (between 18.5 and 25) and the presence of an eating disorder was excluded by administering the SCOFF (Morgan et al., 1999). The patient and control group differed significantly in BMI, $t(51)=-5.01$, $p<.001$, with a mean of 18.96 (SD=2.18) for the patient group and 21.30 (SD=1.76) for the control group. Patients had a mean disease duration of 7.96 (SD=8.34) months.

We asked participants to rate how concerned they were about their arm and abdomen being fat (ratings on a seven-point scale). In both the patient and control group ratings for the abdomen were higher than for the arm, $t_{patients}(24)=-8.22$, $p<.001$ ($mean_{arm}=0.92$, SD=1.29; $mean_{abdomen}=3.16$, SD= 1.21); $t_{controls}(27)=-2.92$, $p=.007$ ($mean_{arm}=0.07$, SD=0.26; $mean_{abdomen}=0.68$, SD=1.06), indicating that indeed, both participant groups were more concerned about their abdomen being fat than their arm. In addition, patients rated both the arm and abdomen higher than controls, $t_{arm}(25.78)=3.23$, $p=.003$; $t_{abdomen}(51)=7.96$, $p<.001$, implying that patients were more concerned about both their arm and abdomen being fat than controls.

2.2. Materials and procedure

2.2.1. Body dissatisfaction

Body dissatisfaction was measured with the Body Shape Questionnaire (BSQ; Cooper et al., 1987) which measures concerns about body shape and size over the past four weeks. Cooper and colleagues (1987) refer to the BSQ as a measure of both body concerns and body dissatisfaction. Here, we will refer to the concept as body dissatisfaction. The BSQ consists of 34 self-report items (e.g. *"Did you avoid social events (such as parties) because you felt bad about your body size?"*) and Cronbach's α in the current sample was 0.98. The experiment always started with the BSQ, the order of the tactile tasks was counterbalanced.

2.2.2. Tactile size estimation

The Tactile Estimation Task (TET; see also Anema et al., 2008; de Vignemont et al., 2005; Keizer et al., 2011; Taylor-Clarke et al., 2004) was used to measure perception of tactile distances. While participants were blindfolded, they received two tactile stimuli with a caliper on either their right underarm (see Figure 1A) or right side of their abdomen (see Figure 1B). Subsequently participants were asked to estimate the distance between the two stimuli by varying the separation between their right thumb and index finger on a Wacom Bamboo Touchpad®, model CTH-661 (see Figure 1C). In order to do so participants needed to access metric information regarding the size of the stimulated body part. As there are no skin-receptors that could have provided participants with information on the *distance* between the two stimuli, participants were required to compare and integrate tactile sensations with a higher order cognitive representation of the size of the touched body part.

For each trial, 100 measurements of the coordinates of the participant's thumb and index finger were registered in MATLAB® (The MathWorks®), based on which the average distance estimation in mm per trial was calculated. The order of the body parts was counterbalanced, and for each body part 15 trials were presented in a random order, with five trials for each presented distance; 50, 60, and 70 mm.

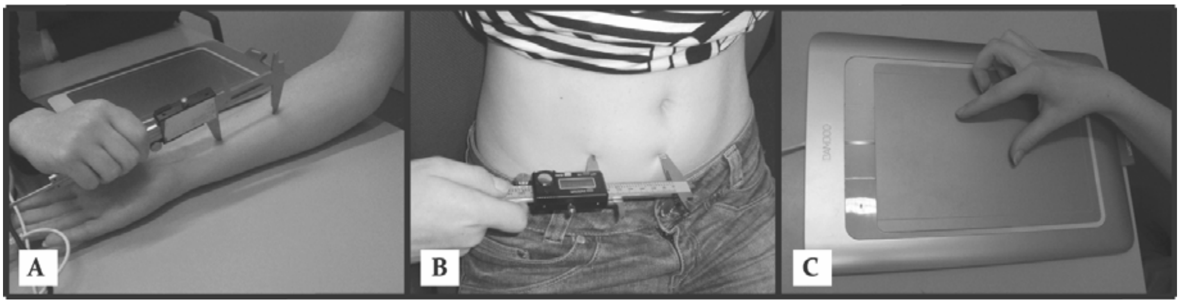

Figure 1. Example trials of the Tactile Estimation Task (TET). Panel A depicts stimuli presentation on the right forearm; panel B depicts stimuli presentation on the right side of the abdomen; and panel C depicts size estimation of the tactile stimuli on a touchpad.

2.2.3. Elementary tactile perception

2.2.3.1. Pressure detection

Using the Von Frey task (VF, see e.g. Fruhstorfer et al., 2001; Weinstein, 1968) the pressure detection threshold was assessed, i.e. the minimum amount of grams force (gf) that was needed for a participant to report perceiving pressure on the skin. The VF task was employed using a Touch-Test™ Sensory Evaluator from Stoelting Co. This kit included 20 filaments, ranging in application force from 0.008 to 300 gf. In each trial either a tactile stimulus was presented with a filament (66% of the trials) on the right underarm or right side of the abdomen on a marked spot, or no stimulus was presented (33% of the trials). Blindfolded participants were asked to indicate whether or not they perceived a stimulus. VF score was determined with a forced choice one up one down staircase (five reversals, Wetherill and Levitt, 1965), the pressure detection threshold was calculated by averaging the filament gf of the last four reversals. For the arm the starting filament required a force of 0.40 gf (Park et al., 2001) and for the abdomen 0.60 gf (based on a pilot study). The order of the body parts tested was counterbalanced.

2.2.3.2. Two point discrimination

The Two Point Discrimination task (TPD, see e.g. Lundborg and Rosen, 2004; Weinstein, 1968) assessed tactile acuity, thus the minimum distance in mm that was needed between two tactile stimuli for a participant to report feeling pressure from two distinct stimuli. In each trial either one (33% of the trials) or two (66% of the trials) tactile stimuli were presented with a caliper on the right underarm or right side of the abdomen. Blindfolded participants were then asked to indicate whether they perceived one single stimulus or two distinct stimuli. Responses were recorded with a forced choice one up two down staircase (five reversals, Wetherill and Levitt, 1965). The two point discrimination threshold was calculated as the average distance between the two pointers of the caliper in the last four reversals of the staircase. For the arm the starting distance was 43 mm and for the abdomen 33 mm (Weinstein, 1968). The order of the body parts was counterbalanced.

3. Results[1]

3.1. Tactile size estimation

The three distances (50, 60, and 70 mm) presented in the TET were averaged because the groups did not show a different distance effect, $F(2,102)=0.56$, $p=.571$. BMI was not included as a covariate as it did not correlate with TET scores, $r_{AN}=-.38$, $p=.061$; $r_{controls}=-.07$, $p=.720$. The mean distance estimation in the TET was 69.82 (SD=12.29) for the patient group ($mean_{arm}=70.87$, SD=12.59; $mean_{abdomen}=68.77$, SD=14.94), and 50.56 (SD=11.36) for the control group ($mean_{arm}=55.78$, SD=13.99; $mean_{abdomen}=45.34$, SD=13.53) (see also Table 1).

A mixed repeated measures ANOVA showed a main effect for group, $F(1,51)=35.16$, $p<.001$, $d=1.65$ and body part, $F(1,51)=1.20$, $p=.002$, $d=0.36$. More importantly, an interaction between body part and group was found, $F(1,51)=4.53$, $p=.039$, $\eta^2=0.07$ (see Table 1 and Figure 2). Post hoc Bonferroni corrected independent samples t-tests indicated that on both the arm $t(51)=4.11$, $p<.001$, $d=0.20$, and abdomen $t(51)=5.99$, $p<.001$, $d=1.70$, distance estimations made by patients were larger than those of controls. Additional post hoc Bonferroni corrected paired samples t-tests showed that distance estimation for the arm and abdomen only differed for the control group, $t(27)=3.55$, $p=.001$, $d=0.77$, but not for the patient group, $t(24)=0.83$, $p=.415$, $d=0.15$.

Taken together, patients made larger distance estimations in the TET than controls on both the arm and the abdomen. Further, the difference in distance

[1] Assumptions for statistical analyses were checked and apart from one, all were met. For the AN group, scores on the VF task (arm condition only) were not normally distributed. We consulted a statistician who indicated that the used analyses are robust to slight deviations from normality, and that it was not necessary to conduct non-parametric analyses (see also Tabachnick, B.G., Fidell, L.S., 2007. Using Multivariate Statistics. Pearson, Boston.).

estimation between the groups was largest on the abdomen, thus the body part that participants were most concerned about in terms of fatness.

Table 1 - Means and standard deviations of all tactile tasks by group and results of the repeated measures ANOVA for all tactile tasks

	AN patients		Controls		Repeated measures ANOVA		
Task	M	SD	M	SD	Effect	F	p
					TET		
TET	69.82	12.29	50.56	11.36	Main effect Group	35.16	<.001
TET arm	70.87	12.59	55.78	13.99	Main effect Body part	1.20	.002
TET abdomen	68.77	14.94	45.34	13.53	Group * Body part	4.53	.039
					VF		
VF	0.23	0.07	0.27	0.11	Main effect Group	2.01	.163
VF arm	0.28	0.12	0.22	0.11	Main effect Body part	0.11	.743
VF abdomen	0.19	0.10	0.32	0.14	Group * Body part	21.27	<.001
					TPD		
TPD	35.79	5.01	32.62	5.15	Main effect Group	4.78	.034
TPD arm	36.52	5.15	34.10	6.73	Main effect Body part	3.21	.080
TPD abdomen	35.06	8.21	31.14	6.20	Group * Body part	0.37	.546

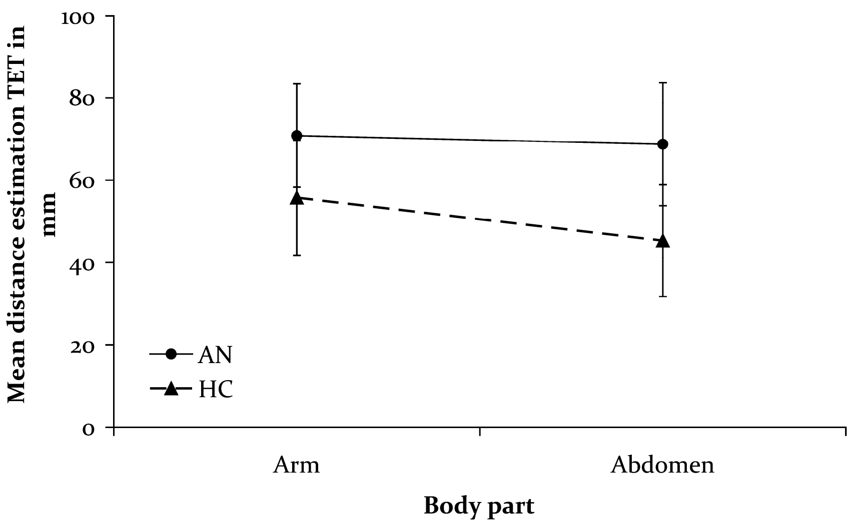

Figure 2. Mean distance estimations in the Tactile Estimation Task (TET) in mm by participant group and body part. Anorexia nervosa (AN) patients estimate tactile distances on both the arm and abdomen as larger than controls do. This effect is largest for stimuli presented to the abdomen. Error bars depict the SD.

3.2. Elementary tactile perception

3.2.1. Pressure detection

The mean VF scores (i.e. pressure detection threshold) of three patients and two controls were extremely high (with means of 0.52; 0.55; 0.65; 1.00; and 1.09 gf) and identified as outliers with the cutoff at three standard deviations from the mean. These participants were removed from the VF analyses. BMI was not included as a covariate as it did not correlate with pressure detection threshold, $r_{AN}=-.42$, $p=.054$; $r_{controls}=.18$, $p=.384$. The mean pressure detection threshold in gf was 0.23 (SD=0.07) for patients ($mean_{arm}=0.28$, SD=0.12; $mean_{abdomen}=0.19$, SD=0.10), and 0.27 (SD=0.11) for controls ($mean_{arm}=0.22$, SD=0.11; $mean_{abdomen}0.32$, SD=0.14) (see also Table 1).

A mixed repeated measures ANOVA showed no main effect for group, $F(1,46)=2.01$, $p=.163$, $\eta^2=0.04$, or body part, $F(1,46)=0.11$, $p=.743$, $\eta^2=0.00$. However, an interaction between body part and group was found, $F(1,46)=21.27$, $p<.001$, $\eta^2=0.32$ (see also Table 1). Post hoc Bonferroni corrected independent samples t-tests showed that patients and controls had significantly different pressure detection thresholds for the abdomen $t(46)=-3.78$, $p<.001$, but not for the arm $t(46)=1.64$, $p=.107$ (see Figure 3). In addition, Bonferroni corrected paired samples t-tests indicated that pressure detection thresholds for the abdomen and arm differed significantly within the patient group, $t(21)=2.46$, $p=.023$, and control group, $t(25)=-4.49$, $p<.001$.

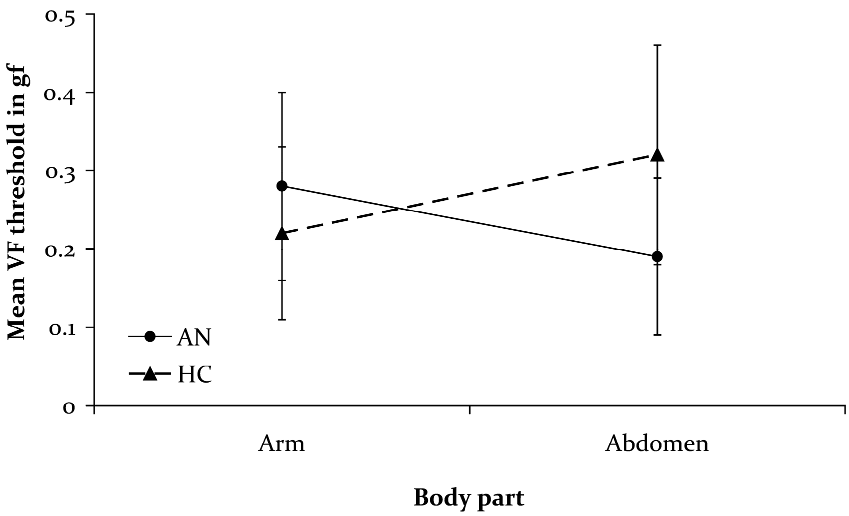

Figure 3. Mean Von Frey (VF) pressure detection thresholds in gf by participant group and body part. Anorexia nervosa (AN) patients and controls perform equally well in detecting pressure on the arm. AN patients have a lower threshold than controls for detecting pressure on the abdomen. Error bars depict the SD.

These results indicate that patients and controls show similar tactile detection thresholds for their arm, but that patients performed better when asked to detect tactile stimuli on their abdomen. In other words, the amount of pressure that had to be applied to the abdomen in order to perceive the stimulus was lower for AN patients than for controls.

3.2.2. Two point discrimination

The mean TPD score (i.e. two point discrimination threshold) on the arm of one of the patients was identified as an outlier (7.00 mm), with a cut-off at 3 standard deviations from the mean. Mean TPD scores on the abdomen of three controls were identified as outliers as well (9.00; 48.25 and 51.50 mm). These participants were removed from the TPD analyses. BMI was not included as a covariate as it did not correlate with two point discrimination threshold, r_{AN}=.24, p=.263; $r_{controls}$=.13, p=.539. The mean two point discrimination threshold was 35.79 (SD=5.01) for patients ($mean_{arm}$=36.52, SD=5.15; $mean_{abdomen}$=35.06, SD=8.21) and 32.62 (SD=5.15) for controls ($mean_{arm}$=34.10, SD=6.73; $mean_{abdomen}$=31.14, SD=6.20) (see also Table 1).

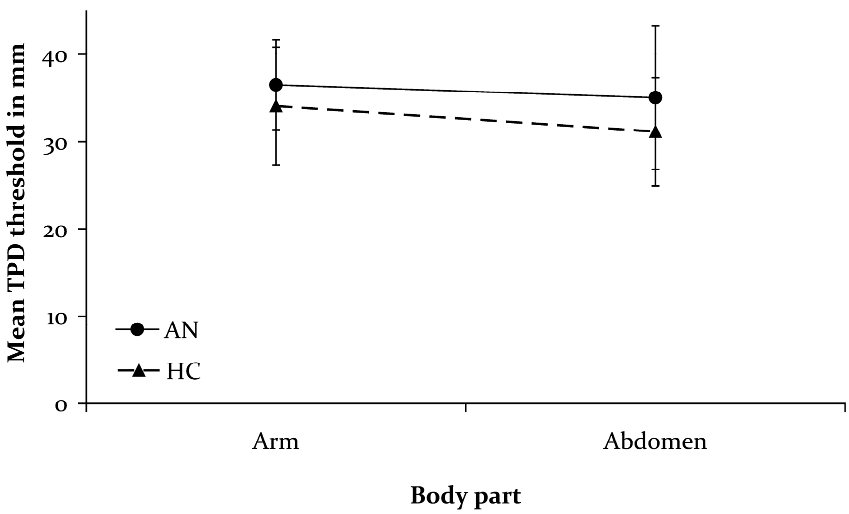

Figure 4. Mean Two Point Discrimination (TPD) thresholds in mm by participant group and body part. Independent of body part, anorexia nervosa (AN) patients have a higher two point discrimination threshold compared to controls. Error bars depict the SD.

A mixed repeated measures ANOVA showed a main effect for group, F(1,47)=4.78, p=.034, d=0.60. Neither a main effect for body part, F(1,47)=3.21, p=.080, d=0.31, nor an interaction between body part and group, $F(1,47)=0.37$, $p=.546$, $\eta^2=0.04$, was found (see also Table 1). These results indicate that, regardless of the body part tested, AN patients had a higher two point threshold than controls (see Figure 4).

3.3. Relation between body dissatisfaction and tactile perception

Patients showed significantly higher levels of body dissatisfaction compared to controls, $t(31.38)=5.97$, $p<.001$, $d=1.72$, with a mean total BSQ score of 85.72 (SD=41.87) for the patients and 31.96 (SD=17.48) for the control group. These results indicate that over the past four weeks patients were more concerned about their body shape and size than controls.

As a main effect for body part was found in the TET analyses, subsequent regression analyses investigating the relationship of tactile size perception (TET) with body dissatisfaction (BSQ), elementary tactile perception (VF and TPD), and group membership (AN or control) were performed for the arm and abdomen separately.

With two Multiple Linear Regression analyses three regression models for the arm and abdomen were tested, see Table 2. Analyses for the arm showed that body dissatisfaction co-occurred with TET distance estimations on the arm, while pressure detection and two point discrimination did not, $R^2=0.21$ (Model 1A, Table 2). However, after including group as a predictor in Model 2A (see Table 2), the relation between body dissatisfaction and TET distance estimation on the arm was no longer significant. Group was a significant predictor, and the explained variance significantly increased to .32, $\Delta R^2=.11$, $p=.011$. Including the interactions between group and body dissatisfaction, pressure detection and two point discrimination in Model 3A (see Table 2) did not result in significant changes in explained variance, $\Delta R^2=.03$, $p=.667$.

Analyses for the abdomen showed that body dissatisfaction, as well as both pressure detection and two point discrimination significantly predicted TET distance estimation on the abdomen, $R^2=.32$ (Model 1B, Table 2). However, after group was added as a predictor in Model 2B (see Table 2), only group and two point discrimination significantly predicted TET distance estimation on the abdomen. The explained variance significantly increased to .58, $\Delta R^2=.26$, $p<.001$. Adding the interaction between group and the remaining predictors in Model 3B (See Table 2) did not result in significant changes in explained variance, $\Delta R^2=.04$, $p=.324$.

Taken together, the regression results imply that group membership (either AN patient or healthy control) is strongly related to distances estimations of tactile stimuli size. Tactile size estimations on the arm were only predicted by group membership, while size estimations on the abdomen were uniquely predicted by both group membership and two point discrimination. Specifically, being diagnosed with AN and having a low two point discrimination threshold predicted larger distances estimation on the abdomen in the TET.

Table 2. Results of the regression analyses by body part.

Dependent variable: TET arm (size estimation)			Dependent variable: TET abdomen (size estimation)		
Predictor Variable	β	p	Predictor Variable	β	p
Model 1A			Model 1B		
BSQ (dissatisfaction)	0.37	**.011**	BSQ (dissatisfaction)	0.34	**.013**
VF arm (detection)	0.24	.092	VF abdomen (detection)	-0.33	**.015**
TPD arm (discrimination)	0.01	.969	TPD abdomen (discrimination)	-0.29	**.031**
Model 2A			Model 2B		
BSQ	0.07	.672	BSQ	-0.11	.435
VF arm (detection)	0.15	.254	VF abdomen (detection)	-0.02	.901
TPD arm (discrimination)	-0.04	.743	TPD abdomen (discrimination)	-0.45	**< .001**
Group	-0.47	**.011**	Group	-0.81	**< .001**
Model 3A			Model 3B		
BSQ (dissatisfaction)	0.04	.852	BSQ (dissatisfaction)	-0.09	.572
VF arm (detection)	0.28	.164	VF arm (detection)	0.22	.334
TPD arm (discrimination)	0.12	.613	TPD arm (discrimination)	-0.39	**.006**
Group	0.29	.767	Group	-0.13	.809
Group * BSQ	0.14	.545	Group * BSQ	-0.15	.422
Group * VF arm	-0.27	.404	Group * VF arm	-0.46	.225
Group * TPD arm	-0.64	.442	Group * TPD arm	-0.27	.575

4. Discussion

Recent work has shown that body representation disturbances in AN are not limited to the visual domain (e.g. Cash and Deagle, 1997), but extend to tactile size perception (Keizer et al., 2011). The current study aimed to investigate whether tactile misperception in AN also involves aberrancies in elementary somatosensory perception.

We successfully replicated the results from our previous study (Keizer et al., 2011), as we found that AN patients overestimated the size of tactile distances compared to controls. In addition, the difference between the groups was most profound for the abdomen. We thus identified tactile misperception in the current sample of AN patients, on a task that depends on a mental representation of the body. Our measures of elementary tactile perception involved detecting pressure on the skin, and two point discrimination (e.g. Weinstein, 1968). The results showed that AN patients and controls did not differ in their ability to detect pressure on their arm. Interestingly, AN patients did have a lower pressure detection threshold on their abdomen than controls, suggesting that they were able to detect smaller amounts of pressure on their abdomen. Thus, AN patients perceived stimuli on their skin that controls did not report to feel. With respect to two point discrimination we found that AN patients had a higher discrimination threshold on both the arm and abdomen compared to controls. In other words, for AN patients the distance between two pressure points needed to be larger in order for them to perceive the stimuli as being distinct, instead of one single stimulus. This suggests larger receptive fields in AN patients on both the arm and abdomen.

Our findings implicate abnormalities on tactile perception and information processing in AN patients at all levels that were tested. Overestimation of tactile distances might resemble a tactile variant of the disturbance in body representation often identified in AN patients in visual tasks (e.g. Cash and Deagle, 1997), which has been linked to influences of top-down processes (Keizer et al., 2011; Smeets and Kosslyn, 2001). However, in order to detect pressure or to discriminate between two pressure points on the skin a representation of body size is not accessed (Spitoni et al., 2010). Firing of specific populations of receptor neurons provide this type of elementary somatosensory information directly (Spitoni et al., 2010). This implies that on a basic level of tactile perception AN patients and controls differ as well.

A second aim of the current study was to explore how tactile size estimation related to body dissatisfaction and measures of elementary tactile perception. The regression results imply that differences in body dissatisfaction or elementary tactile perception between AN patients and controls are in itself not sufficient to explain differences in tactile size estimation. This allows us to exclude the possibility that bottom-up processes are solely responsible for overestimation of tactile stimuli in AN.

Our regression results specifically showed that group membership (i.e. either AN patient or control) predicted size estimation on the arm. Size estimations on the abdomen were predicted by group membership and two point discrimination. This suggests that overestimation of tactile distances is related to AN pathology in the broader sense, which includes a whole range of symptoms involving both lower and higher order processing, such as body dissatisfaction, low body fat (Polito et al., 1998), disturbed eating behaviour (APA, 2000), and altered attentional processing (Fassino et al., 2002). We therefore propose that both bottom-up and top-down information could influence and distort the mental representation of body size that is tapped into when making tactile size judgments. Unrelated to AN, it has been suggested that both bottom-up and top-down information is used to construct the mental body representation (Dijkerman and de Haan, 2007; Serino and Haggard, 2010). It was previously found that conceptual information such as body dissatisfaction can influence and distort the (visual) mental representation of body size in AN (Smeets, 1997). Here we establish that AN patients show abnormalities in *both* aspects required for creating an accurate mental representation of body size: They are not only highly dissatisfied with their body, but also show aberrant low level tactile processing.

The current study does not offer a direct explanation for differences in both higher order and elementary tactile perception between the patient and control group. It should be noted here that AN patients and controls differ in physical characteristics. For example, AN patients have a lower body weight and body temperature (Miller et al., 2005), and a different composition of fat mass and fat-free mass (Dellava et al., 2009; Polito et al., 1998). Such differences might influence receptor functioning related to pressure detection and two point discrimination and thus underlie, in a bottom-up fashion, the shown group differences in tactile size estimation. This might also explain why AN patients and controls performed equally well in detecting pressure on the arm, but differed in detecting pressure on the abdomen. During the course of AN physical changes due to weight loss affect both the arm and abdomen. However, the magnitude of for example loss of fat tissue is larger on the abdomen than on the arm for some AN patients (De Álvaro et al., 2007).

Furthermore different pathways are associated with the tactile tasks. For example, pressure detection is related to superficial sensibility, while two-point discrimination is related to deep sensitivity. Different pathways may have different relationships to higher cognitive systems, and thus could result in performance differences between the tactile tasks.

On the other hand, differences in performance between body parts in the pressure detection task and size estimation task might also be related to top-down processes. AN patients' haptic pattern perception, both before and after weight gain, is worse than that of controls (Dellava et al., 2009). Furthermore, somatosensory and haptic (pattern) perception seem unrelated to BMI (Grunwald et al., 2001; see also the current study). We suggest that the level of concern participants had about either body part being fat might be important. We showed that AN patients were more concerned about their abdomen being fat than controls. Such concerns have been linked to increased attention towards, and extreme preoccupation with, body(part) size and shape (Grant et al., 2002). It is likely that the AN patients in the current study directed more attention towards their body in general (APA, 2000), and their abdomen specifically, than the healthy controls, as the experimental setting involved being blindfolded while the body was visible to the experimenter. Directing spatial attention to touch has been shown to facilitate (elementary) tactile processing (see Spence and Gallace, 2007 for a review). This may be modulated by affective processes: Presenting threatening cues, such as images of snakes results in faster tactile discrimination compared to presenting nonthreatening cues, such as images of flowers. The facilitating effect of threatening cues was modulated by fear of snakes reported by the participants (Poliakoff et al., 2007). Although the current study did not involve cueing, it could be that the experimental set-up was perceived as more fear-provoking by AN patients than controls. It would then be expected that AN patients would perform better on the elementary tactile tasks than controls. This is in line with the results from the pressure detection task, as AN patients indeed performed better than controls when detecting pressure on their abdomen.

Counterintuitively, AN patients did not perform better on two-point discrimination, and increased attention did not result in decreased deviations from a "normal" response in the size estimation task. This suggests that AN patients' performance on these tasks did not benefit from enhanced tactile attention. Apparently the speculated effects of attention on somatosensory perception in AN might not affect all spatial tactile tasks in the same manner. Future research should clarify the role(s) that attentional processes might play in tactile perception in AN.

Taken together, our findings underscore the importance of body representation disturbances at the somatosensory level in the phenomenology of

AN. In addition we showed that AN patients and controls do not only differ in higher order somatosensory processing, but also at the level of elementary tactile perception. Thus AN patients perceived and interpreted touch sensations on their skin different than controls, regardless of whether a metric representation of body size was involved. It is beyond the scope of the current study to draw conclusions regarding the processes responsible for these differences between AN patients and controls. Nevertheless, the current results imply that in treatment the focus should not exclusively be on normalizing eating behaviour and cognitions. AN is among the most severe and treatment resistant psychiatric disorders (Fichter et al., 2006; Harris and Barraclough, 1998; Rosling et al., 2011), taking into account inappropriate mental body representations as a whole, thus also at the level of somatosensory perception, might result in more effective treatment approaches. To conclude, our results suggest that when AN patients state they are feeling fat this is not a mere reflection of their emotions and cognitions towards their body, but also based on an actual differences in perceptual experiences of tactile stimulation.

Acknowledgements
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CHAPTER 5

Walking through apertures: Do you know what you are doing during body-scaled action?

Anouk Keizer
Suzanne E.M. De Bruijn
Monique A.M. Smeets
Chris Dijkerman
Albert Postma

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Abstract

We investigated whether body-scaled action is influenced by awareness of task performance. Participants walked through apertures varying in size. Awareness of performing the action was manipulated by asking half of the participants to concurrently perform a haptic memory task. Distracted participants showed a smaller maximum amount of shoulder rotation at A/S_{crit}. Walking through apertures thus seems a rather automatic/uniform process regarding action-planning, but being distracted from performing the action appears to influence *how* the action is performed, and may increase its efficiency.

During locomotion safe, collision-free, movement requires fast and accurate determination of whether adjustment of postural movements is necessary. Warren and Whang (1987) identified the critical *aperture (A) to shoulder (S) ratio* (A/S_{crit}), i.e. the relative width of an opening for which individuals start to rotate their shoulders in order to fit through. Ever since, body-scaled action has been widely studied (e.g. Fajen and Matthis, 2011; Franchak et al., 2012; Higuchi et al., 2011; Wilmut and Barnett, 2010). Notably, in these studies participants knew the purpose of the study was aperture crossing, which may have attracted conscious attention to what traditionally has been assumed to be an automatic process. The main objective of the current study was therefore to investigate whether body-scaled action can be influenced by participants' conscious awareness of the aim of the study.

Specifically, participants walked through apertures varying in width (see Figure 1 for set-up). Half of the participants (n=15) knew what the purpose of the study was (aware group), which enabled them to make a conscious decision regarding their shoulder width and rotation. The other participants (unaware group) were told the study investigated haptic memory. At the start of each walking trial unaware participants explored and memorized a relief structure. At the end of the walking trial they explored two different structures located behind the apertures, and selected which one was identical to the first relief structure. Unaware participants were told we investigated whether movement (walking) would interfere with a memory-task also involving movement (exploring relief structures), and that explorative hand-movements and exploration time were the main study variables. To increase reason-to-believe we placed fake markers on the participants' elbows, wrists, and hands. Unaware participants were further instructed to focus their attention on memorizing haptic stimuli, thereby directing attention away from the apertures they walked through. Apertures were referred to as "panels" and only mentioned during the instructions in which unaware participants were told the panels could change location but that at all times they should walk in a straight line through the room, using the midpoint between the panels as a guide. The aware participants received similar walking instructions, only they *did* know shoulder rotation was of interest. After study completion participants were asked what they thought the study purpose was, whether they noticed anything about the "panels", and used a specific strategy during the experiment. None of the unaware participants guessed that shoulder rotation was the actual variable of interest, nor mentioned using strategies affecting walking and/or rotation.

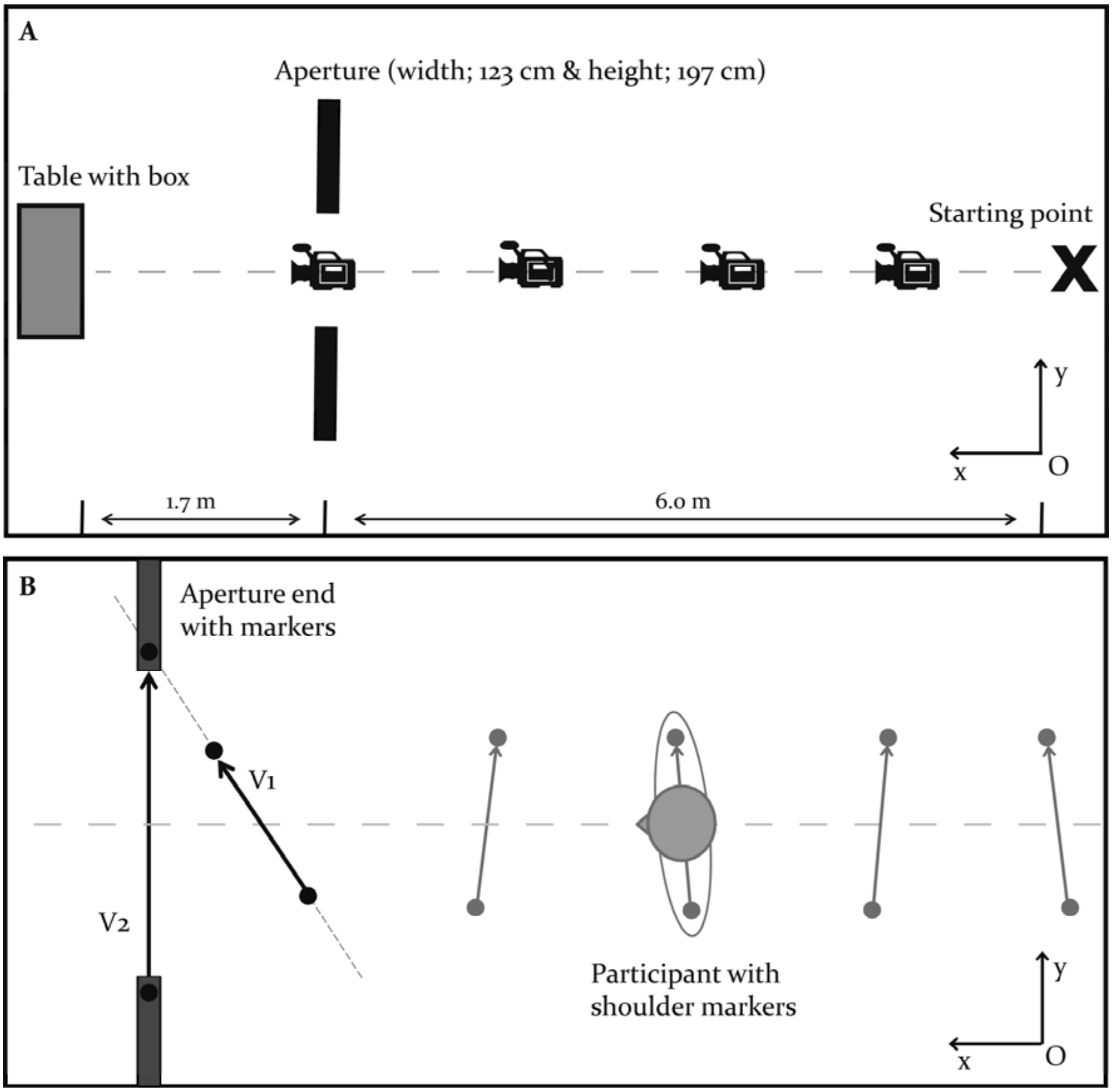

Figure 1. Set-up aperture task

Panel A. Participants walked from the starting point towards a table placed behind the aperture (two grey movable MDF partitions). Aperture width was based on participants' shoulder width. Twelve different aperture widths were randomly presented three times, ranging from A/S=0.9 to A/S=2.0 (in steps of A/S=0.1), making a total of 36 trials. Rotation trials were defined as shoulders' angle being larger than natural sway within one meter before or half a meter behind the aperture. Natural sway was defined as maximum angle of shoulder rotation from starting point till one meter before the aperture. A/S_{crit} was defined as widest aperture for which participants rotated their shoulders at least two out of three trials. Four OptiTrack™ cameras (V100:R1) recorded passive reflective markers on the shoulders and MDF partitions at 100Hz.

Panel B. Angle of the shoulders relative to the partitions was calculated as an angle between two vectors (V1 and V2). The coordinates of the middle point between the shoulder and aperture markers were considered a measure of position of either the participant or aperture.

Independent samples t-tests (see Table 1) showed that the aware and unaware groups did not differ in A/S_{crit} i.e. they started rotating their shoulders at the same relative aperture width. Further, the groups did not differ in average walking speed over all trials. For rotation trials, no group differences were found on maximum amount of shoulder rotation at A/S=0.9. The groups did however differ on maximum amount of shoulder rotation at A/S_{crit}. A trend was found for onset of shoulder rotation at A/S=0.9 and A/S_{crit}.

Table 1. Results

	Aware group (n=15)		Unaware group (n=15)			
	M	SD	M	SD	t(df=28)	p
A/S_{crit}	1.18	0.08	1.21	0.10	0.80	.430
Mean walking speed (km/h)	6.10	0.58	6.57	0.69	1.54	.136
Max rotation A/S=0.9 (in °)	67.67	14.31	63.48	15.02	-0.78	.441
Max rotation A/S_{crit} (in °)	43.04	20.62	25.72	11.87	-2.82	.010
Onset rotation A/S=0.9 (in cm from aperture)	86.18	15.84	73.50	21.99	-1.81	.081
Onset rotation A/S_{crit} (in cm from aperture)	63.35	31.63	48.68	22.90	1.94	.062

Note. Walking speed df=26 (missing data for two participants), maximum shoulder rotation A/S_{crit} df=22.36 (Levene's test significant).

Taken together, aware participants showed a higher maximum shoulder rotation at A/S_{crit} than unaware participants. This implies that conscious awareness of the study purpose does not influence action-planning or selection per se (i.e. the relative aperture width for which participants start to rotate their shoulders), but rather *how* the action is performed. This is also reflected by marginally significant results indicating earlier onset of shoulder rotation for aware participants, i.e. they rotated their shoulders in a more anticipatory manner.

As unaware participants did not report strategies that reduced their body movements and minimized hypothetical interference with the haptic memory task, we deem it unlikely that the memory task instructions biased our results. Future studies should focus on whether other tasks/instructions indeed reveal results similar to those found here.

Although conscious attention is usually thought to impact upon the ventral stream, visual processing for action execution (dorsal stream) can be influenced by attention as well (Milner and Goodale, 2006). Here, unaware participants appeared to be more efficient, as they made smaller shoulder rotations at A/S_{crit}. This suggests that walking through apertures is a highly automatized skill that is not necessarily improved but may even be hampered by allocating conscious attentional resources.

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CHAPTER 6

Too fat to fit through the door: First evidence for disturbed body-scaled action in anorexia nervosa during locomotion

Anouk Keizer
Monique A.M. Smeets
Chris Dijkerman
Siarhei A. Uzunbajakau
Annemarie van Elburg
Albert Postma

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Abstract

To date, research on the disturbed experience of body size in anorexia nervosa (AN) mainly focused on the conscious perceptual level (i.e. *body image*). Here we investigated whether these disturbances extend to *body schema*: an unconscious, action-related representation of the body.

AN patients (n=19) and healthy controls (HC; n=20) were compared on body-scaled action. Participants walked through door-like openings varying in width while performing a diversion task. AN patients and HC differed in the largest opening width for which they started rotating their shoulders to fit through. AN patients started rotating for openings 40% wider than their own shoulders, while HC started rotating for apertures only 25% wider than their shoulders.

The results imply abnormalities in AN even at the level of the unconscious, action oriented body schema. Body representation disturbances in AN are thus more pervasive than previously assumed: They do not only affect (conscious) cognition and perception, but (unconscious) actions as well.

1. Introduction

Body representation disturbances are considered a key-symptom of anorexia nervosa (AN, APA, 2000; Keel et al., 2005; Killen et al., 1996; Stice, 2002; Stice and Shaw, 2002), and found to be persistent, even after otherwise successful treatment (Carter et al., 2004; Exterkate et al., 2009). The current study shows that body representation disturbances in AN are even more pervasive than previously assumed, and go beyond a distorted (mental) *image* of the body. Specifically, we show here that action-guidance in AN patients is based on enlarged body size input. Thus, AN patients do not only think that they are fat, and perceive themselves as fat, even their motor behaviour is consistent with such beliefs and perceptions, as patients were found to walk through a door-like opening as if they were fatter than they actually are. Our study is the first that directly targets action-related body representation disturbances in AN.

Previous research on the disturbed experience of body size and shape in AN has focused mostly on body related deviancies in cognition/affect and (body size) perception. Typically AN patients show high levels of body dissatisfaction (e.g. Cash and Deagle, 1997; Smeets, 1997; Smeets et al., 1997) and visually perceive/imagine their body as fatter than it is (e.g. Garner, 2002; Skrzypek et al., 2001; Smeets and Kosslyn, 2001). To ensure optimal treatment, we believe it is crucial to gain insight into all facets of body representation disturbances in AN. For example, recently it was found that AN patients' tactile perception is altered as well: Patients perceived tactile stimuli on their skin as further apart than they actually were (Keizer et al., 2011; Keizer et al., 2012). However, no studies have yet directly addressed body representation disturbances in AN beyond perceptual processing, and focused on the possibility that body representation disturbances could extend to more unconscious, *action*-related, aspects of body representation. This is surprising, as body-scaled action may be affected by an inappropriate mental representation of body size.

Body-scaled action is closely linked to the so-called *body schema*. Traditionally, in literature on body representation a distinction is made between body image and body schema (de Vignemont, 2010). We adopt here the definition of body schema as an unconscious, sensorimotor, representation of the body that is invoked in action (de Vignemont, 2010; Dijkerman and de Haan, 2007; Gallagher, 2005; Haggard and Wolpert, 2005; Paillard, 1999). It is believed to store, and constantly update, information on e.g. the exact location of the body and its parts in space, and on how separate parts of the body form a coherent whole (e.g. Haggard and Wolpert, 2005). Body schema aids action guidance by providing information on where the body is in space, and given its size, which actions it affords relative to obstacles in the environment (de Vignemont, 2010; Stefanucci and Geuss, 2009). Body image on the other hand is its conscious counterpart that is mainly used in body-size related perception and (affective) cognition (de Vignemont, 2010; Dijkerman and de Haan, 2007; Gallagher, 2005; Paillard, 1999). Note however that different researchers adopt different definitions of body schema (see e.g. de Vignemont, 2010). Body schema may be used to refer to mainly postural information and somatic input concerning the location of a tactile stimulus on the skin (Longo et al., 2010), but is has also been be used as an umbrella term which encompasses body form representations as well, instead of only action-related processing (Medina and Coslett, 2010).

In the present study we measured body-scaled action by having participants walk through door-like openings varying in width. To do this safely and efficiently, participants need to access information on the location and size of their body relative to external objects (Warren and Whang, 1987). Constant updating and processing of this information is suggested to take place outside awareness, which enables individuals to perform actions like navigating past obstacles/other individuals relatively effortlessly (de Gelder et al., 2008). In general, individuals successfully rotate their body as soon as an open space is smaller than the widest frontal dimension of their body, without investing much conscious effort.

The possibility of body schema disturbances in AN has been suggested previously (Guardia et al., 2012a; Guardia et al., 2010; Nico et al., 2010). For example, a motor imagery study, in which participants *imagined* walking through a projected aperture, showed that AN patients indicated they would rotate their shoulders for relatively larger apertures than healthy controls (Guardia et al., 2010). This was interpreted as indicative of a body schema disturbance (Guardia et al., 2010). It should be noted that participants did not actually perform the action of walking in this study. Importantly, in this previous work (Guardia et al., 2010) it cannot be ruled out that AN patients made a conscious decision about having to rotate their shoulders or not. Such a conscious decision might reflect AN patients' emotional/cognitive state towards their body; i.e. "I am fat, thus I will not fit through this opening without rotating". A direct assessment of the body schema in action at a more implicit level has not been made yet in AN. In the current study we therefore assessed actual *walking* through an aperture, while having participants focus their attention on a diversion task, and not on their rotating behaviour, ensuring a relatively unconscious measurement of body schema. As AN patients are overly aware of their body (size), we aimed to distract them from how they moved their body in space as much as possible, and presented the apertures as “panels” with no apparent significance.

Previous findings with healthy participants have shown that the width of an opening for which participants start to rotate their body in order to fit through can be expressed as critical aperture (A) to shoulder (S) ratio (A/S_{crit}) (Warren and Whang, 1987). For example, with an individual shoulder width of 40 cm, and rotation starting at an aperture width of 50 cm, A/S_{crit}=1.25 (50/40). A/S_{crit} was found to be constant across healthy participants, independent of body height or width (Warren and Whang, 1987). In accordance with motor imagery findings (Guardia et al., 2012a; Guardia et al., 2010) we hypothesized that AN patients would show a higher A/S_{crit} than healthy controls, i.e. that AN patients would start to rotate their shoulders at relatively larger openings than healthy controls would.

2. Methods

2.1. Ethics statement

The current study was approved by two independent ethics committees (Medical Ethical Committee University Medical Centre Utrecht and the Committee Scientific Research of Altrecht Rintveld Eating Disorders). The study adhered to the tenets of the Declaration of Helsinki. Each participant received an information letter about the study and the study procedures. At the start of the experiment the procedures were verbally explained by the researcher, after which written informed consent from the participant was obtained.

2.2. Participants

Thirty-nine females, over 18 years of age, and without physical conditions preventing them from walking, participated: 19 patients (13 AN patients and 6 eating disorder not otherwise specified patients (EDNOS), APA, 2000), and 20 healthy undergraduate students. Presence of an eating disorder was excluded in healthy controls (HC) using the Eating Disorder Examination Questionnaire (EDE-Q; Fairburn and Beglin, 1994). AN and EDNOS patients were diagnosed with the Eating Disorder Examination (EDE; Fairburn and Cooper, 1993) and a psychiatric interview. Patients received treatment as usual ranging from daily to weekly sessions at an eating disorder clinic. Treatment aimed at weight gain, and due to increased BMI at the time of the study, some patients' initial AN diagnosis changed to EDNOS. However, it was found that EDNOS is similar to AN (Machado et al., 2007; Williamson et al., 2002), and that a combined AN/EDNOS group is homogeneous (e.g. Rodriguez-Cano et al., 2009). Indeed, here AN and EDNOS patients did not have different scores on any of the tasks (see results section). Therefore we will refer to the AN/EDNOS group as the AN patient group or patient group.

AN patients and HC did not differ in age, $t(25.01)=-2.97$, $p=.127$ ($M_{AN=}23.68$, $SD=4.62$; $M_{HC}=21.90$, $SD=2.13$). HC had a higher BMI than AN patients, $t(36.96)=-2.98$, $p=.001$ ($M_{AN}=18.32$, $SD=2.69$; $M_{HC}=21.00$, $SD=1.55$). Disease duration for AN patients ranged from 2 to 50 months ($M=15.00$, $SD=14.04$). Note that patients may have received treatment elsewhere as well.

2.3. Materials and procedure

The experiment started with measuring body height, shoulder height and the horizontal width between the shoulders, waist, elbows, hips, and knees. Participants were told infrared cameras hanging from the ceiling would record reflective markers that would be placed on their body, from which their movements throughout the experiment could be inferred, and that the body measurements were necessary to calibrate these cameras. In reality only measures of shoulder height and width were used for this purpose. After completion of the aperture task, perceptual body image was assessed by asking participants to estimate their body width and their shoulder width, to verify perceptual body size representation disturbances in the AN group.

2.3.1. Aperture task

Each trial (see Figure 1) started with the participant standing on the starting point. Participants walked 7.7 meters towards a table placed behind an aperture. Six meters from the starting point the participants walked through the aperture, which consisted of two grey movable wooden partitions (197 x 123 mm). After each trial, participants waited behind a screen while the experimenter prepared the set-up for the following trial. In total 36 trials were completed, consisting of 12 different aperture widths that were each presented three times. Aperture width was based on the actual shoulder width of the participants, and ranged from A/S=0.9 to A/S=2.0, in steps of A/S=0.1. Using a tailored MATLAB® (The MathWorks®) routine, aperture width was determined, and the trials were presented in a randomized order.

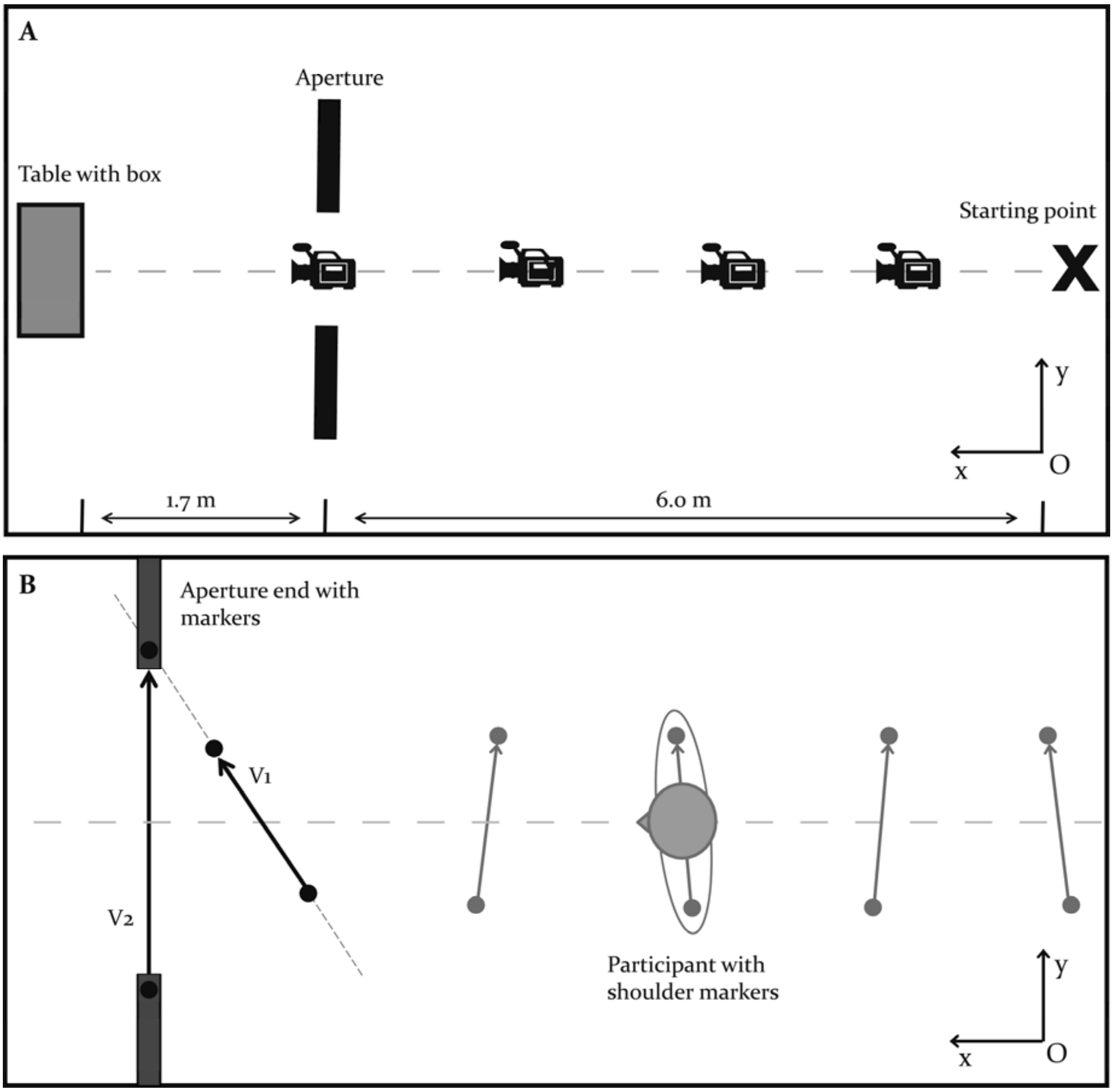


Figure 1. Schematic set up of the aperture task (Panel A) and calculation of shoulder rotation (Panel B).
Panel A: "Starting point" refers to the marked spot on the floor where each participant stood on at the beginning of a trial; "Aperture" refers to the wooden partitions forming an opening that varied in size; "Table with box" refers to the endpoint of each trial, on which a box was placed that was used as part of the haptic memory distracter task.
Panel B: V1 and V2 refer to the vectors calculated in the global coordinate system. The amount of shoulder rotation was defined by calculating the angle between V1 and V2.

Four Optitrack™ cameras type V100:R1 recorded (100 Hz) two passive reflective markers (12.7 x 12.7 cm) that were placed on the shoulders of the participants (on top of the humerus) and on the edges of the partitions. The angle of the shoulders relative to the partitions was calculated for each trial using a tailored MATLAB® routine. In the calculations, a global two-dimensional coordinate system was assumed to coincide with the floor of the room. The origin of the global coordinate system was assumed to be located at the right bottom corner of the field of view of the first camera (denoted as "O" in Figure 1). Coordinates of all markers in the global coordinate system were calculated for each recorded frame based on positions of the markers in the fields of view of the cameras and height-dependent scaling coefficients. The scaling coefficients were determined by recording a system of markers located on the floor of the room and by measuring height of the markers on the participants' shoulders and that of the markers on the partitions. Subsequently, two vectors (denoted as V1 and V2 in Figure 1) were calculated in the global coordinate system. Vector V1 points from the left to the right shoulder marker. Similarly, vector V2 points from the left to the right partition marker. The angle of the shoulders relative to the partitions was calculated as an angle between vectors V1 and V2 (see Figure 1). The coordinates of the middle point between the markers on the shoulders of the participant, as well as the markers on the partitions, were considered as a measure of the position of the participant and the aperture.

When the angle of the shoulders was larger than the natural sway in between one meter before and half a meter behind the aperture, a participant was said to have rotated her body in order to fit though the opening. Natural sway was defined as the maximum angle of shoulder rotation from starting point till one meter before the aperture. A/S_{crit} was defined as the widest aperture for which a participant rotated her shoulders at least two out of three trials. Mean walking speed in km/h was determined over all trials. For rotation trials the maximum angle of shoulder rotation and onset of shoulder rotation were calculated. Onset of shoulder rotation was defined as the distance (in cm) from the aperture at which shoulder rotation was first larger than the natural sway. For both variables we were mainly interested in performance at A/S=0.9, the smallest aperture width for which each participant had to rotate, otherwise she would not be able to fit through it, and performance at $A/S_{crit.}$

Participants were unaware of the actual purpose of the study (i.e. measuring shoulder rotation while crossing apertures), and were led to believe the experiment focused on haptic memory. At the start of each walking trial participants explored a relief structure (10 x 2.5 cm; based on Kahrimanovic et al., 2009) and were instructed to memorize the pattern. At the end of the walking trial, participants explored two relief structures placed in a box at the table located at the end of the room, and chose which one was most similar to the one explored at the beginning of the trial. Participants were told the walking enabled the researchers to investigate whether performing a different action (exploration with hands vs. walking) would influence haptic memory. Apertures were referred to as panels and only mentioned in the walking instructions: "*Walk in a straight line towards the table, using the midpoint between the panels as a guide. The panels may change location during the experiment, e.g. from left to right, or front to back. You are assigned the condition in which they move from left to right. Please walk as natural as possible, you can walk and move however you prefer, as long as you walk in a straight line towards the table.*" The experiment was thus presented as investigating haptic memory by analyzing how participants explored the haptic patterns, and whether exploration could be influenced by performing a different action (walking) in between the first (start of walking trial) and second (end of walking trial) exploration. To make it more convincing that explorative hand movements were of interest, fake markers were placed on the participants' hands, wrists, and elbows. At the end of the aperture task participants completed a questionnaire assessing the study objectives in which we explicitly asked what they thought the aim of the study was, and whether they noticed anything about the apertures ("panels"), the table in the room, and the box containing the haptic patterns. All participants indicated that they thought the main aim of the experiment was related to haptic memory, and described strategies for exploring and memorizing the different structures. None of the participants guessed that we were actually interested in measuring shoulder rotation, neither did they notice anything other than the panels moving across trials about the apertures.

2.3.2. Body image

Perceptual body image was assessed after the aperture task by asking participants to estimate their body width, as well as their shoulder width specifically. To assess general body size estimation participants stood on the starting point with aperture width set at A/S=2.0. The experimenter pushed the partitions closer together and the participant indicated when she would be able to fit exactly in the space between the apertures. This was repeated while the aperture was closed and the experimenter pulled the partitions apart. The average width of the pushing and pulling condition was taken as a measure of body size estimation. To assess shoulder width specifically, participants were instructed to draw a vertical line on a whiteboard which represented the width of their shoulders. We choose a vertical line in this task, because when drawing a horizontal line, participants could have easily used their own body as a reference while drawing.

3. Results

3.1. Aperture task

AN patients had a significantly higher A/S_{crit} than HC, $t(37)=3.84$, $p<.001$ ($M_{AN}=1.40$, $SD=0.15$; $M_{HC}=1.25$, $SD=0.09$), implying that AN patients rotated their shoulders for relatively larger apertures than HC. A/S_{crit} did not correlate with BMI, $r_{AN}=.18$, $p=.466$; $r_{HC}=.08$, $p=.724$, disease duration, $r_{AN}=.07$, $p=.800$, or walking speed, $r=-.14$, $p=.416$. Independent samples t-tests showed that AN patients and HC differed on walking speed over all trials, $t(35)=-2.67$, $p=.011$ ($M_{AN}=5.98$, $SD=0.53$; $M_{HC}=6.41$, $SD=0.47$). The groups did not differ on mean maximum angle of rotation at $A/S=0.9$ and A/S_{trials} trials, and onset of rotation at $A/S=0.9$ and A/Sc_{rit} trials (see Table 1).

Table 1. Results for the aperture task, shoulder width measurement, and shoulder width estimation by group.

	AN (n=19)		HC (n=20)			
	M	SD	M	SD	t(37)	p
A/S_{crit}	1.40	0.15	1.25	0.09	3.84	<.001
Walking speed (km/h)	5.98	0.53	6.41	0.47	**-2.67	.011
Max rotation A/S=0.9 (in °)	72.00	12.10	68.05	13.33	*0.96	.345
Max rotation A/S_{crit} (in °)	32.37	18.55	31.86	18.08	0.09	.932
Onset rotation A/S=0.9 (cm from aperture)	75.72	24.03	76.08	29.22	*-0.04	.967
Onset rotation A/Sc_{rit} (cm from aperture)	61.39	19.33	48.80	24.60	1.77	.085
Absolute aperture width at A/S_{crit} (cm)	51.91	7.86	49.42	4.20	1.27	.213
Shoulder width (cm)	37.03	2.82	39.55	2.16	-3.15	.003
Estimated shoulder width (cm)	47.08	9.66	43.68	8.47	-0.30	.767
Overestimation shoulder width (%)	27.85	28.03	10.68	22.42	2.12	.041

Note. * refers to a df of 36 due to missing data in the HC group (n=1), **refers to a df of 35 due to missing data in the HC group (n=1) and an outlier in the AN group (n=1).

Although we grouped AN and EDNOS patients together in the current experiment, we checked for differences between these groups, but found none. Most importantly, there were no significant differences between AN and EDNOS patients for A/S_{crit}, $t(17)=-0.65$, $p=.523$ ($M_{AN}=1.39$, $SD=0.16$; $M_{EDNOS}=1.43$, $SD=0.15$). AN and EDNOS patients also did not differ with regard to other variables associated with the aperture task and locomotion: Walking speed in km/h, $t(17)=0.19$, $p=.848$ ($M_{AN}=6.30$, $SD=1.62$; $M_{EDNOS}=6.17$, $SD=0.49$); maximum rotation in degrees at $A/S=0.9$, $t(17)=0.13$, $p=901$ ($M_{AN}=72.25$, $SD=13.43$; $M_{EDNOS}=71.47$, $SD=9.66$); maximum rotation at A/S_{crit} in degrees, $t(17)=0.57$, $p=.579$ ($M_{AN}=34.03$, $SD=21.13$; $M_{EDNOS}=28.76$, $SD=11.97$); onset of rotation at $A/S=0.9$ in cm from aperture, $t(17)=-0.30$, $p=.770$ ($M_{AN}=74.57$, $SD=15.60$; $M_{EDNOS}=78.20$, $SD=38.51$); onset of rotation at A/S_{crit} in cm from aperture, $t(17)=0.65$, $p=.524$ ($M_{AN}=63.38$, $SD=19.08$; $M_{EDNOS}=57.07$, $SD=20.96$); and absolute aperture width at A/S_{crit} in cm $t(17)=.19$, $p=.848$ ($M_{AN}=50.73$, $SD=8.00$; $M_{EDNOS}=54.48$, $SD=6.86$).

Taken together, the patient group and HC group differed in the opening size for which they started rotating, but behaved quite similar on other aspects of locomotion.

3.2. Body image

Note that all analyses reported below were, unless stated otherwise, independent samples t-tests. AN patients had significantly smaller shoulders than HC, $t(37)=-3.15$, $p=.003$ ($M_{AN}=37.03$ cm, $SD=2.82$; $M_{HC}=39.55$, $SD=2.16$), see Table 1. To take this difference in actual shoulder width into account we calculated the percentage of overestimation as 100*(estimated-actual)/actual (see Longo and Haggard, 2010).

The results from the general body size estimation task (indicating body width by adjusting the aperture) showed a between-group difference, with AN patients showing significantly higher percentages of overestimation of their body size than HC, $t(37)=5.02$, $p<.001$ ($M_{AN}=46.29\%$, $SD=15.08$; $M_{HC}=23.54\%$, $SD=13.23$). One sample t-tests showed that both AN patients and HC significantly overestimated their body size, $t_{AN}(18)=13.38$, $p<.001$; $t_{HC}(19)=7.96$, $p<.001$. Percentage of body size overestimation correlated with disease duration, $r_{AN}=-.54$, $p=.017$, but not with BMI, $r_{AN}=.16$, $p=.503$; $r_{HC}=-.11$, $p=.631$. When comparing the absolute aperture width (in cm) for which participants started rotating their body (i.e. width of the aperture in cm at A/S_{crit}) with the absolute estimation of body size (in cm) using paired samples t-tests we did not find differences for the AN patients, $t_{AN}(18)$= 1.01, p=.325 nor HC, $t_{HC}(19)$=-.39, p=.700.

More importantly, in the body image task in which shoulder width was specifically estimated by drawing a line on a whiteboard, AN patients showed higher percentages of overestimation than HC, t(37)=2.12, p=.041 (M_{AN}=27.85%, SD=28.03; M_{HC}=10.68%, SD=22.42), see Table 1. One sample t-tests showed that both groups overestimated their shoulder width, $t_{AN}(18)$=4.33, p<.001; $t_{HC}(19)$=2.13, p=.047. Size estimation of shoulder width (body image measure) did not correlate with A/S_{crit} (body schema measure), r_{AN}=-.35, p=.146; r_{HC}=.07, p=.786. For AN patients, but not HC, shoulder width estimation correlated with BMI, r_{AN}=-.54, p=.017; r_{HC}=-.26, p=.268. No correlation between estimation of shoulder width and disease duration was found, r_{AN}=-.23, p =.352.

A/S_{crit} from the aperture task was based on the largest aperture width for which participants rotated at least two times (A) divided by the participants' shoulder width (S). AN patients and HC did not differ on the absolute value of A in cm, t(37)=1.27, p=.213 (M_{AN}=51.91 cm, SD=7.68; M_{HC}=49.42 cm, SD=4.20), see Table 1. Instead of using S to calculate A/S_{crit}, $A/S_{estimated\_crit}$ can be determined as well. $A/S_{estimated\_crit}$ refers to the largest aperture width for which participants rotated at least two times (A) divided by the participants' absolute *estimate* of her shoulder width in cm in the body image task ($S_{estimated}$). $A/S_{estimated\_crit}$ is thus a parameter indicative of what participants' ratio would be if their shoulders were in reality as wide as they estimated them to be. AN patients and HC did not differ in $A/S_{estimated\_crit}$, t(37)=-0.30, p=.767 (M_{AN}=1.14, SD=0.28; M_{HC}=1.17, SD=0.22). In addition, when comparing HC's A/S_{crit} with AN's $A/S_{estimated\_crit}$ there were no significant differences, t(21.46)=-.1.59, p=.127 (M_{AN}=1.14, SD=0.28; M_{HC}=1.25, SD=0.09). In other words, if AN patients' shoulders were to be as wide as they estimated them to be, their performance on the aperture task would be the same as that of HC.

Taken together these results show that both AN patients and HC overestimate their general body size as well as their shoulder width specifically, although the percentage of overestimation was higher for AN patients. Based on estimated shoulder width, performance on the aperture task would have been comparable to normal in AN patients.

4. Discussion

Previous research on body representation disturbances in AN has mainly focused on perceptual body image disturbances (see e.g. Cash and Deagle, 1997; Skrzypek et al., 2001), while studies on action-related components of body representation are relatively absent. To ensure optimal treatment and understanding of the disturbed experience of body size in AN, it is important to know the extent of this disturbance, i.e. is it limited to the perceptual body image, or does it extend to action-related body schema? Therefore, the present study assessed potential disturbances in body-scaled action in AN patients. Body-scaled action was measured with an aperture task (see e.g. Warren and Whang, 1987), with as main parameter of interest the critical aperture (A) to shoulder (S) ratio (A/S_{crit}), i.e. the relative width of the aperture for which participants started to rotate their shoulders in order to fit through (Warren and Whang, 1987). The results clearly showed that AN patients had a higher A/S_{crit} than HC, indicating that AN patients rotated their shoulders for relatively larger openings than HC (A/S_{crit} 1.40 vs 1.25).

The current results are a first demonstration of AN patients having a disturbance in body-scaled action, as their adaptive postural changes during body-scaled action appeared to be based on an enlarged representation of body size. The results further revealed that AN patients, compared to HC, showed a higher percentage of overestimation of their shoulder width in a perceptual body image task in which they drew a line representing the distance between their shoulders. In addition, we calculated $A/S_{estimated\_crit}$ based on the absolute aperture opening for which participants started rotating in the aperture task (A) and their absolute *estimated* shoulder width ($S_{estimated}$). Interestingly, these results suggest that if AN patients' shoulders were as wide as they estimated them to be, they would perform equal to HC on body-scaled action. This implies that stored information on body size is disturbed in AN, which in turn affects perception-related body image as well as action-related body schema representations.

The present study provides two critical extensions compared to previous work. First, in contrast to the study by Guardia et al. (2010), we measured real action performance. Second, during the aperture task participants were unaware of the aim of the study, as they focused their attention on memorizing haptic patterns. Although AN patients are chronically aware of their body (size) (APA, 2000), it is unlikely that here their decision to either rotate while crossing an aperture, or walk straight through, was consciously influenced by negative affective/emotional top-down input related to their body size. When explaining the procedures and during the experiment participants were led to believe the objective of the study was assessing haptic memory. Great care was taken to minimize the apparent significance of the apertures, which were referred to as “panels” and mentioned as little as possible. In addition, would AN patients have made such conscious rotating decisions, this would likely have affected other typical locomotor adjustments associated with crossing an aperture such as onset of rotation or amount of rotation (e.g. Higuchi et al., 2006; Wilmut and Barnett, 2010). We did not find differences on these variables between AN patients and HC. The results did show a small difference in walking speed, with AN patients walking slightly (less than half km/h) slower than HC. As AN patients’ A/S_{crit} was higher than that of HC, AN patients rotated on *more* trials than HC during the experiment. Previous research showed that trials on which participants rotate their shoulders results in decreased walking speed, compared to non-rotation trials (Wilmut and Barnett, 2010), which is likely to explain reduced walking speed in the AN group. Overall, it appears that during action motor-programs process information accurately, but the body size related *input* they receive is not in accordance with actual body dimensions of the AN patients.

As also suggested by e.g. Guardia et al. (Guardia et al., 2012a; Guardia et al., 2010) body schema disturbances in AN may be related to a failure to update body-schema to new (smaller) body dimensions after initial weight-loss. Our patient group consisted of a combination of AN and EDNOS patients. Indeed, the AN patients in our sample have lost weight over time, and their body schema might not be updated to their now (extremely) small body size. In contrast, the EDNOS patients included in our sample entered treatment diagnosed with AN (i.e. underweight), but gained weight during treatment, resulting in no longer fulfilling the diagnostic criteria for AN due to a healthy BMI and body size at the time of the experiment. In other words, the EDNOS patients did not *have* smaller body dimensions that their body schema should have been updated to. Still their A/S_{crit} was found to be higher than that of HC, and did not differ from AN patients’ A/S_{crit}. This deems failure to update body schema to smaller body dimensions an unlikely explanation for patients’ higher A/S_{crit}. Future studies investigating body-scaled action in healthy participants who lost (or gained) a significant amount of weight could shed more light on the issue of updating body schema to changed body dimensions and its possible influence on body-scaled action.

The present study further raises questions regarding the relation between disturbances in body-size related perception and action. Should AN patients' altered body-scaled action be viewed as separate from previously identified disturbances in body image (e.g. Keizer et al., 2011; Skrzypek et al., 2001; Smeets and Kosslyn, 2001), could either one be causally linked to the other, or is perhaps the relation between body image and body schema distortions more dynamic? Literature on body representations does not offer a conclusive answer on this matter. Although the two concepts – body image and body schema – are traditionally viewed as two separate representations (see e.g. Dijkerman and de Haan, 2007; Gallagher, 2005; Paillard, 1999), it has also been suggested that perception and action cannot be viewed as completely independent (see e.g. de Vignemont, 2010; Stefanucci and Geuss, 2009). In other words, we might be able to distinguish between different body representations that play different roles in different situations, but they nevertheless interact and overlap with each other, as encoding of bodily information depends on task demands, e.g. which information is required in a certain context (de Vignemont, 2010).

It is beyond the scope of this paper to resolve the body image vs body schema issue. However, the current study does imply that body size related distortions in AN are more pervasive than previously assumed, and that they affect not only perception, but action as well, which has important implications for treatment. Usually the aim of interventions targeting the disturbed experience of the body in AN is changing cognitions and perception of body size. Several studies have shown that such approaches are not always efficient, as after otherwise successful treatment, body-size issues remain (Exterkate et al., 2009). This may be because current interventions mainly attempt to change aspects of body image, and not of body schema. It could therefore be relevant to design a treatment strategy in which action related responses are targeted as well. Interventions focusing on sensorimotor feedback, for example prism adaptation, were already found to be successful in influencing action as well as perceptual representations in hemispatial neglect (Frassinetti et al., 2002) and complex regional pain syndrome patients (Bultitude and Rafal, 2010).

In sum the present study suggests that when crossing an aperture AN patients used, on an implicit level, body size information congruent with how they perceive themselves, instead of their actual (smaller) body dimensions. It thus appears that for AN patients experiencing their body as fat goes beyond thinking and perceiving themselves in such a way, it is even reflected in how they move around in the world. This indicates that the disturbed experience of body size in AN is more pervasive than previously assumed.

CHAPTER 7

Does the experience of ownership over a rubber hand change body size experience in anorexia nervosa patients?

Anouk Keizer
Monique A.M. Smeets
Albert Postma
Annemarie van Elburg
Chris Dijkerman

Article under review

Abstract
Anorexia nervosa (AN) patients show disturbances in body size experience. Here, malleability of body representation was assessed by inducing the Rubber Hand Illusion (RHI). Specifically the impact of the illusion on body size estimation was investigated. Twenty-eight AN patients and 28 healthy females participated. The RHI was induced synchronously (experimental condition) and asynchronously (control condition) Both before and after induction of the RHI participants were asked to estimate the size of their own and the rubber hand. The results showed that AN patients had a stronger experience of ownership over the rubber hand than healthy females. No group difference on proprioceptive drift was found. Before induction of the illusion AN patients overestimated hand and wrist width. After induction of the illusion (experimental as well as control condition) AN patients no longer overestimated the width of their hand. Healthy females correctly estimated hand size both before and after induction of the RHI. In conclusion, stronger experience of ownership over the rubber hand in the AN group implies a more malleable body representation in AN patients compared to healthy females. Changed hand size estimation in the AN group appears to be unrelated to the RHI, as it occurred in both the experimental and control condition of the illusion, alternative interpretations are discussed.

1. Introduction

One of the key-features of anorexia nervosa (AN) is a disturbed experience of body weight and shape (see e.g. Cash and Deagle, 1997; Skrzypek et al., 2001; Smeets et al., 1997). This is traditionally referred to as a disturbance in body image. An increasing number of researchers has taken an interest in understanding this phenomenon from a neuro(psycho)logical viewpoint (e.g. Faris et al., 1992; Friederich et al., 2010; Grunwald et al., 2001; Grunwald et al., 2002; Guardia et al., 2012b; Miyake et al., 2010; Mohr et al., 2010; Nico et al., 2010; Suchan et al., 2010; Wagner et al., 2003). Notably, recent studies have shown that the disturbed experience of body shape and size in AN is not limited to thinking about the body as bigger than it actually is, and visually perceiving it as such, but that it extends to altered performance on tasks involving tactile perception (e.g. Keizer et al., 2011; Keizer et al., 2012), haptic perception (e.g. Grunwald et al., 2001; Grunwald et al., 2002; Guardia et al., 2012b) as well as action-oriented tasks (e.g. Guardia et al., 2012a; Guardia et al., 2010; Keizer et al., 2013; Nico et al., 2010). Thus it appears that body (size) representation disturbances can be identified in multiple modalities. What is yet unclear is whether this disturbed body representation can be experimentally manipulated. This is an important question as current treatment approaches focusing on the disturbed experience of body size in AN have not been very successful (e.g. Exterkate et al., 2009). These therapeutic interventions mainly focus on visual processing of bodily information. Perhaps a more multisensory approach offers new insights into body representations in AN that can be used in treatment. Previous studies with healthy participants suggest that multisensory *bodily illusions* are an excellent way of increasing our understanding of the plasticity of the representation of the body in the brain.

Eshkevari and colleagues (2012) were among the first to investigate differences between AN patients and healthy females using a bodily illusion. They found that AN patients are more susceptible to the Rubber Hand Illusion (RHI) than healthy females. The RHI is an illusion in which participants experience ownership over a fake rubber hand once the rubber hand and (occluded) own hand are stimulated in synchrony (see e.g. Botvinick and Cohen, 1998; Ehrsson et al., 2005a; Kammers et al., 2009). This experience of ownership arises as a result of visuotactile integration; as soon as there is a temporal match between visual input (seeing a rubber hand being stroked) and tactile input (at the same time feeling the actual hand being stroked), the brain integrates the two events into a single event, which gives participants the illusionary experience that the felt touch occurs on the rubber hand, and that this hand belongs to their body (Botvinick and Cohen, 1998). The strength of the illusion is measured on a subjective self-report level with a questionnaire (see e.g. Longo et al., 2008), but also on a perceptual level using proprioceptive drift. Proprioceptive drift refers to a shift in the reported location of the index finger after induction of the illusion, i.e. the felt position of the hand has "drifted" towards the rubber hand (Botvinick and Cohen, 1998). Note that the illusion only occurs when the rubber hand and actual hand are stimulated in synchrony, but not during asynchronous stimulation, which is often included as a control condition (e.g. Kammers et al., 2009).

Eshkevari and colleagues (2012) concluded that a stronger experience of the illusion in AN patients points to increased plasticity of the bodily self. The authors (2012) related this to increased sensitivity for visual aspects of body perception in this group (e.g. viewing the body from an appearance-based perspective rather than a competence-based perspective), which in turn may result in increased visual capture. In other words, characteristics inherent to AN might enhance dominance of visual input over proprioceptive input during the RHI, resulting in a stronger experience of the rubber hand belonging to the own body. The authors further supported this conclusion with the finding that AN patients show a stronger effect on the RHI in both the synchronous and asynchronous (control) condition, implying AN patients' excessive focus on visual information.

Interestingly, the RHI can be used to manipulate body size experience. For example, Haggard and Jundi (2009) induced the RHI using a big and small rubber hand in a healthy population, and afterwards asked participants to estimate the weight of an object by placing it in the hand of the participants. They found that participants perceived objects to be heavier after induction of the RHI with a big hand compared to a small hand. They thus induced a Size Weight Illusion (SWI): Although the objects were identical in weight during the big and small rubber hand condition, participants perceived the object to be heavier in the big rubber hand condition, as the object was smaller relative to the big rubber hand (Haggard and Jundi, 2009). This suggests that during the RHI participants do not only experience ownership over the rubber hand, and perceive the location of their hand to have drifted towards the location of the rubber hand, but also that the size of the rubber hand is incorporated into the mental representation of the body. Although not directly assessed, these findings imply that after successful induction of the RHI participants regard their own hand as equal in size to the rubber hand (Haggard and Jundi, 2009). This is in accordance with reports of Longo and colleagues (2008) who found that participants experience the rubber hand not as an additional limb, but as a replacement of their own hand (see also Moseley et al., 2008a). In addition Longo and colleagues (2009) argue that the subjective experience of the illusion results in greater perceived similarity between the own and rubber hand (Longo et al., 2009).

This is a particularly interesting line of reasoning in relation to AN, as AN patients experience their body size unrealistically. Would it be possible to change body size experience in an AN group using a bodily illusion such as the RHI? To answer this question we *directly* assessed the effect of the RHI on perceived hand-size by asking AN patients as well as healthy participants to estimate the size of the rubber hand and their own hand, both before and after induction of the RHI. Increased insight into whether the experience of body size can be changed in AN is crucial, as the disturbed experience of body size has been linked to the development and maintenance of AN (Stice, 2002; Stice and Shaw, 2002). In addition, the enlarged experience of body size in AN is very persistent, and not corrected by accurate visual input (e.g. in a mirror) or after otherwise successful treatment (Exterkate et al., 2009). In clinical settings AN patients for example report that treatment focused at improving body size experience using visual input (e.g. mirrors) can indeed result in visually perceiving their body more accurately, but that it does not eliminate the *experience* of being bigger altogether. Patients indicate that they learn to cope with feeling bigger than they are, but that the experience of such feelings still remains after treatment.

The aim of the present study was twofold. The first aim was to replicate Eshkevari and colleagues' (2012) traditional RHI study. Based on their results we expected that AN patients would have a stronger experience of the RHI than healthy females (Eshkevari et al., 2012). Second we investigated the effect of the RHI on the experience of body (hand) size. AN patients show altered processing of information related to their own body (Guardia et al., 2012a; Sachdev et al., 2008; Wagner et al., 2003). The literature further indicates that although AN patients do not have a general deficit in estimating the size of objects or bodies of others, they overestimate their own body size (Guardia et al., 2012a; Slade and Russell, 1973). After successful induction of the RHI the rubber hand is no longer an external object but experienced as part of the own body. This would allow for the hypothesis of AN patients overestimating the size of the rubber hand after induction of the RHI, as it is no longer an external object, but part of the own body. However, would the change in identity of the rubber hand (i.e. not mine vs. mine) also affect the experience of actual body size? Assuming that AN patients will initially overestimate own hand size, size estimations made after induction of the RHI can change in two directions, either they become smaller (i.e. more accurate) or overestimation remains. Researchers suggest that after induction of the RHI, the size of the rubber hand is incorporated into the mental representation of the body (Haggard and Jundi, 2009; Longo et al., 2009; Moseley et al., 2008a). Following Haggard and Jundi's (2009) conclusions from a study with healthy participants, it may be expected that participants will estimate the size of their own hand as equal to the size of the rubber hand after the illusion. Here, AN patients would thus be expected to correct their assumed initial overestimation of hand size, i.e. size estimations would decrease.

2. Methods

2.1. Participants

Sixty females participated on the basis of written informed consent. Four participants (two AN patients and two healthy controls (HC)) did not experience the illusion and were considered outliers based on their subjective rating of the RHI (2 SD below the mean) and self-report. They were removed from the dataset and reported analyses are based on data of 28 HC and 28 AN patients (18 AN patients and 10 eating disorder not otherwise specified (EDNOS) patients). Note that some patients with an initial AN diagnosis gained weight during the course of treatment, resulting in an EDNOS diagnosis at the time of testing. The AN and EDNOS patients did not differ on any of the outcome variables of the current experiment, therefore we will refer to them from here on as "the AN group".

Four AN patients were left-handed, as were six HC. Mean age for AN patients was 26.68 (SD=9.30) and 21.68 (SD=2.37) for HC, $t(30.50)=2.76$, $p=.010$. Age did not correlate with any of the variables of interest (all Bonferroni corrected p's >.037). Mean BMI was 17.48 (SD=2.19) for AN patients and 21.22 (SD=2.07) for HC, $t(54)=-6.57$, $p<.001$. Patients received treatment as usual at a specialized eating disorder clinic. Mean disease duration for AN patients was 9.5 months (SD=12.95), note that patients may have received treatment elsewhere as well.

2.2. Embodiment Questionnaire

The Embodiment Questionnaire (EQ; based on Botvinick and Cohen, 1998; Kammers et al., 2009) assessed the subjective experience of the RHI by letting participants rate ten statements on a ten-point Likert-scale ranging from 1 "I strongly disagree" to 10 "I strongly agree" (see Table 1 for the statements). The first three statements have been shown to specifically measure experience of ownership over the rubber hand, and were consistently rated above 5 "neutral" in previous studies (see Botvinick and Cohen, 1998; Kammers et al., 2009). The remaining seven statements provide additional information on individual illusion experience, such as vividness (see e.g.Kammers et al., 2009).

2.3. Proprioceptive drift

To measure proprioceptive drift, the experimenter moved a small metal bar (length: 45 cm) alongside the back of the RHI set-up, and participants were instructed to say "stop" as soon as the location of the metal bar matched the location of the middle point of their index finger. Participants judged their finger location before and after induction of the RHI, while their own hands and the rubber hand were occluded from view. The difference between estimated location of the index finger before and after induction of the RHI constituted as proprioceptive drift. A larger bias in proprioceptive judgment towards the rubber hand (positive value) indicates larger visual dominance of the rubber hand over proprioceptive information of the actual hand. Note that the synchronous (i.e. synchronous stroking over rubber hand and actual hand) and asynchronous (control) condition (i.e. out of sync stroking over rubber hand and actual hand) of the RHI were both induced twice in the current experiment, in analyses we used the average proprioceptive drift over the two synchronous inductions as well as the average over the two asynchronous inductions.

2.4 Size estimation

Participants were asked to estimate the size of the both the rubber hand and their own hand before and after induction of the RHI. Before the induction of the RHI participants viewed the rubber hand for 30 sec, after which the rubber hand was occluded from view. Participants then estimated the width of the rubber hand, the width of the wrist of the rubber hand, and the length of the rubber hand. The order was counterbalanced over participants. For each size estimation the experimenter moved the two pointers of a caliper alongside the back of the RHI set-up. The hands of the experimenter were not visible during size estimation. Participants made their size judgment by indicating when each part of the rubber hand would fit exactly in between the two pointers of the caliper. Before induction of the illusion participants made two size judgments: Once while the two pointers of the caliper moved away from each other, and once while the two pointers moved towards each other. The order was counterbalanced over participants. Afterwards, participants made identical size estimations for their actual (unseen) hand.

After induction of the RHI, this procedure was repeated for the rubber and own hand, except that after each induction of the RHI the participants made one instead of two size estimations, to prevent fatigue in the patient group. In the synchronous as well as asynchronous condition the pointers of the caliper once moved closer together and once moved away from each other. The order was counterbalanced over participants. Note that within one participant the order of the parts of the hand that had to be estimated, and the order of estimating rubber and own hand were not counterbalanced.

2.5 Procedure

For a schematic overview of the procedures, see Figure 1. At the start of the experiment participants filled out a general demographic questionnaire. Subsequently, participants were seated behind a desk and were asked to remove any jewelry from their hands and wrists. Procedures of inducing the RHI were based on Botvonick and Cohen (1998) and Kammers and colleagues (2009). On the desk stood a wooden box (77.5 x 50.0 x 23.5 cm) in which a left rubber hand was placed on a marked cap (26.5 cm away from the side of the box). By placing a board vertically in the box, two compartments could be created, which occluded the actual hand from view while the rubber hand remained visible (see Figure 2A). The box could be closed off by placing a board on top (see Figure 2B). While their hands were placed in their lap, so they could not be seen, participants viewed the rubber hand for 30 sec. Then the experimenter closed the box, and participants made size estimations of the width, width of the wrist and length of the rubber hand. While their hands remained in their lap, participants made the same size estimations for their actual hand.

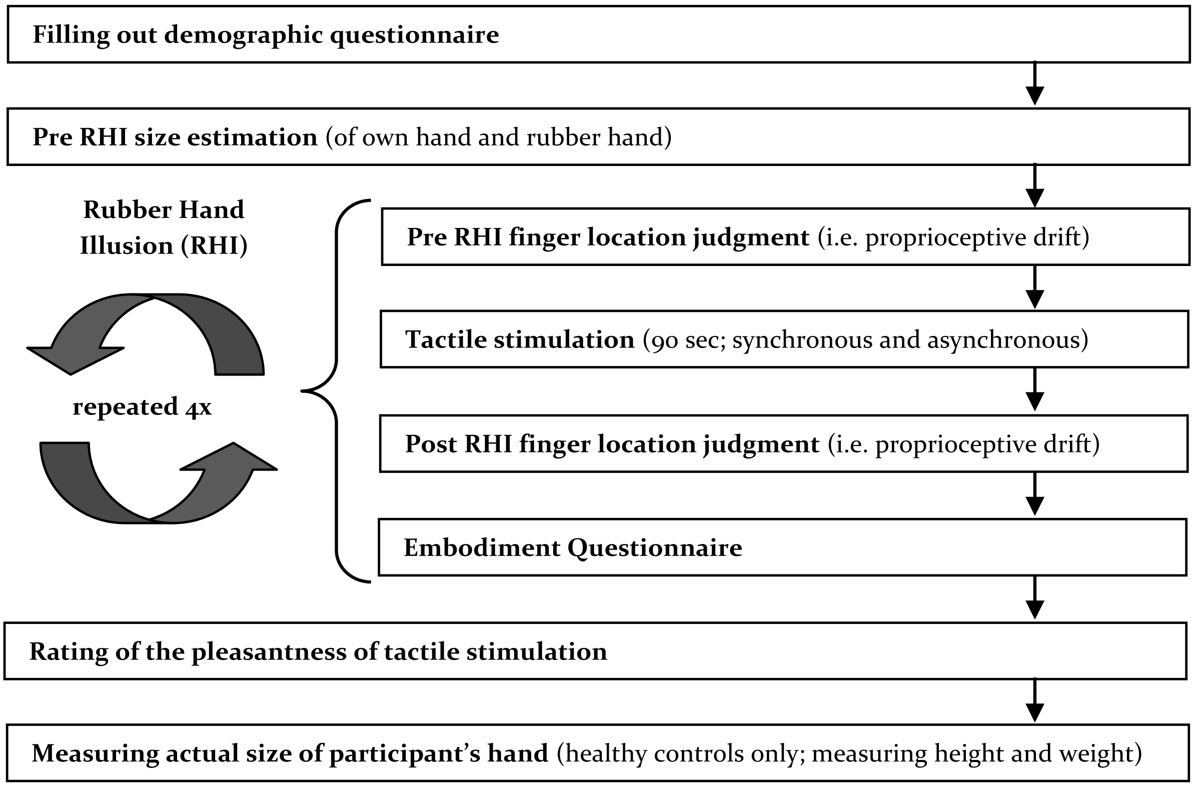


Figure1. Schematic depiction of the experimental procedures

With the board still on top of the box, a black cloth was placed over the shoulder and arm if the participants, it also covered the end of the rubber hand. Participants placed their actual left hand in the box on a marked cap (17.5 cm away from the rubber hand), in a similar position as the rubber hand was in (guided by the experimenter, see Figure 2). Note that the right hand of the participants remained in their lap during the experiment, as it otherwise might have influenced size estimations during the experiment. The RHI was induced a total of four times, twice while the experimenter synchronously stimulated the rubber and actual hand, and twice asynchronously (control condition). The order of these conditions was counterbalanced. At the start of each induction of the RHI participants were asked to indicate the location of their index finger (to assess proprioceptive drift). Then, they closed their eyes, and the horizontal board on the box was replaced by the vertical one. The experimenter stroked the rubber hand and actual hand with a soft brush for 90 sec, during which the participants were instructed to watch the rubber hand lying in front of them, and keep their own hands as still as possible. After tactile stimulation the participants closed their eyes again, and the experimenter placed the horizontal board on the box. The participants opened their eyes, and first judged the location of their index finger, then made size estimations of the rubber hand and their actual hand, and filled out the EQ.

After the RHI was induced four times the participants rated the pleasantness of being touched with the brush on their hand on a ten-point Likert scale ranging from 1 "very unpleasant" to 10 "very pleasant". The experimented ended with measuring the actual size of the hand of the participants with a caliper, and for the HC group, measuring height and weight. For AN patients the most recent height and weight measurement from their medical file was used.

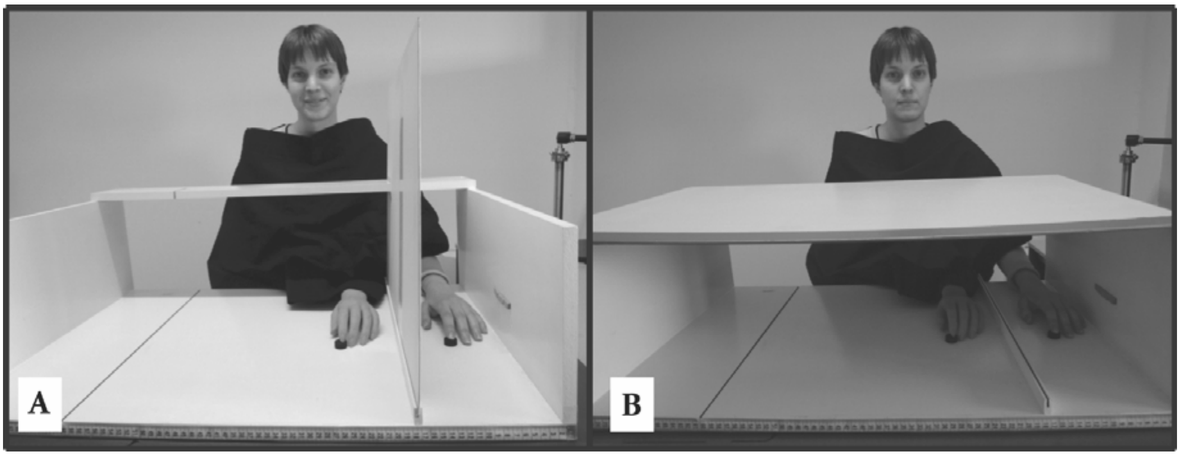


Figure 2. Panel A depicts the Rubber Hand Illusion (RHI) set-up with a vertical board, occluding only the actual hand (the hand on the far right in the picture) from view. Panel B depicts the RHI set-up with a horizontal board, occluding both the rubber hand and actual hand from view.

3. Results

3.1. Embodiment Questionnaire

The EQ measured the subjective experience of the RHI, i.e. whether and to what extent participants experienced the rubber hand as their own hand. Mean ratings of each statement of the EQ by condition (synchronous vs asynchronous) and group (AN vs HC) can be found in Table 1. Only data of statements resulting in significant differences in mean ratings across the synchronous and asynchronous condition, and with a mean rating above 5 "neutral" in either group (AN or HC), will be discussed here (see Kammers et al., 2009).

With these statements we created an "ownership" subscale (cronbach's α: .81) and "vividness" subscale (cronbach's α: .88). The ownership subscale consisted of

Table 1. Statements, mean ratings and SD's on the Embodiment Questionnaire by condition and group. Results of Bonferroni corrected paired samples t-tests (critical p=.008) are reported for statements rated above "neutral"/"5" in either the AN or HC group

	AN patients (n=28)						HC (n=28)					
	Synchronous		Asynchronous		df=27		Synchronous		Asynchronous		df=27	
	M	SD	M	SD	t	p	M	SD	M	SD	t	p
1. It seemed as if I was feeling the touch at the location where I saw the rubber hand being touched.	9.13	1.09	3.96	2.64	8.71	.000	7.91	2.45	3.73	2.23	8.27	.000
2. It seemed as though the touch I felt was caused by the stimulation on the rubber hand.	8.45	1.58	3.96	2.28	8.39	.000	6.96	2.48	3.46	2.03	7.22	.000
3. I felt as if the rubber hand was my own hand.	7.52	2.24	3.34	2.66	5.74	.000	6.02	2.57	3.52	2.07	5.20	.000
4. I felt as if my real hand was drifting towards the rubber hand.	5.54	2.52	3.88	2.54	3.45	.002	3.98	2.29	3.11	2.16	2.51	.008
5. It felt as if I had more than one hand.	2.39	1.97	2.48	1.70	n/a	n/a	2.04	1.45	1.91	1.37	n/a	n/a
6. It seemed as if the touch I was feeling came from in between my own hand and the rubber hand.	3.23	2.42	2.66	.192	n/a	n/a	2.36	1.16	2.66	2.01	n/a	n/a
7. It felt as if my real hand was turning "rubbery".	3.70	2.63	3.07	2.06	n/a	n/a	3.18	2.40	2.52	1.99	n/a	n/a
8. It appeared (visually) as if the rubber hand was drifting towards my own hand.	3.46	2.52	3.18	1.80	n/a	n/a	2.39	1.73	2.21	1.54	n/a	n/a
9.The rubber hand began to resemble my own real hand, in terms of shape, skin tone, freckles, etc.	5.43	3.08	4.50	2.50	2.91	.007	4.98	2.55	3.36	1.84	3.48	.002
10. It felt as if the rubber hand and my own hand lay closer together.	5.38	2.95	3.16	2.43	2.81	.009	4.27	3.12	3.55	2.30	1.96	.060

the mean score on item one, two and three, which for AN patients was 8.36 (SD=1.35) in the synchronous condition and 4.27 (SD=2.18) in the asynchronous condition. For HC mean ownership subscale score was 6.96 (SD=2.33) in the synchronous condition and 3.57 (SD=1.85) in the asynchronous condition. The higher the mean score, the more strongly the participant experienced ownership over the rubber hand. The vividness subscale consisted of the mean score on item four, nine, and ten, which for AN patients was 5.45 (SD=2.25) in the synchronous condition and 4.18 (SD=2.30) in the asynchronous condition. For HC mean vividness subscale score was 4.41 (SD=1.86) in the synchronous condition and 3.34 (SD=1.97) in the asynchronous condition (see Figure 3). The higher the mean score, the more vivid the experience of ownership over the rubber hand was.

A 2 (condition: synchronous vs asynchronous) x 2 (scale: ownership subscale vs vividness subscale) x 2 (group: AN vs HC) mixed repeated measures ANOVA indicated a significant main effect for condition, $F(1,54)=39.89$, $p<.001$ and subscale, $F(1,54)=109.21$, $p<.001$, and a significant condition*scale interaction, $F(1,54)=80.21$, $p<.001$. More interestingly, a significant main effect for group was found, $F(1,54)=5.90$, $p=.019$. The condition*group interaction, $F(1,54)=0.06$, scale*group interaction, $F(1,54)=0.90$, and condition*scale*group interaction, $F(1,54)=0.79$ were not significant. Taken together these results are in accordance with previous results of Eshkevari and colleagues (Eshkevari et al., 2012) implying that AN patients had a stronger experience of ownership over the rubber hand than HC, as well as a more vivid experience of the illusion, in both the synchronous and asynchronous condition. As for ratings of pleasantness of tactile stimulation, AN patients and HC did not differ ($M_{AN}=8.64$, SD=1.45; $M_{HC}=8.50$, SD=1.23, $t(54)=0.40$, $p=.692$).

3.2. Proprioceptive drift

Proprioceptive drift measured the perceptual experience of the RHI, i.e. the extent to which participants experienced a shift in the felt position of their actual hand towards the rubber hand. In the synchronous condition mean proprioceptive drift was 2.40 cm (SD=2.38) for AN patients, and 1.90 cm (SD=3.49) for HC. In the asynchronous condition mean proprioceptive drift was 1.10 (SD=1.76) for AN patients and 0.27 cm (SD=2.08) for HC. A 2 (condition: synchronous vs asynchronous) x 2 (group: AN vs HC) mixed repeated measures ANOVA showed a significant main effect for condition, $F(1,54)=22.40$, $p<.001$. No main effect for group was found, $F(1,54)=1.24$, $p=.270$, nor a condition*group interaction, $F(1,54)=0.29$, $p=.596$. Taken together proprioceptive drift was larger in the synchronous vs asynchronous condition, irrespective of group (AN vs HC), indicating that the illusion was successfully induced in both groups. In contrast to findings by Eshkevari and colleagues (Eshkevari et al., 2012) we did not observe a larger proprioceptive drift in the AN group compared to the HC group in the present study.

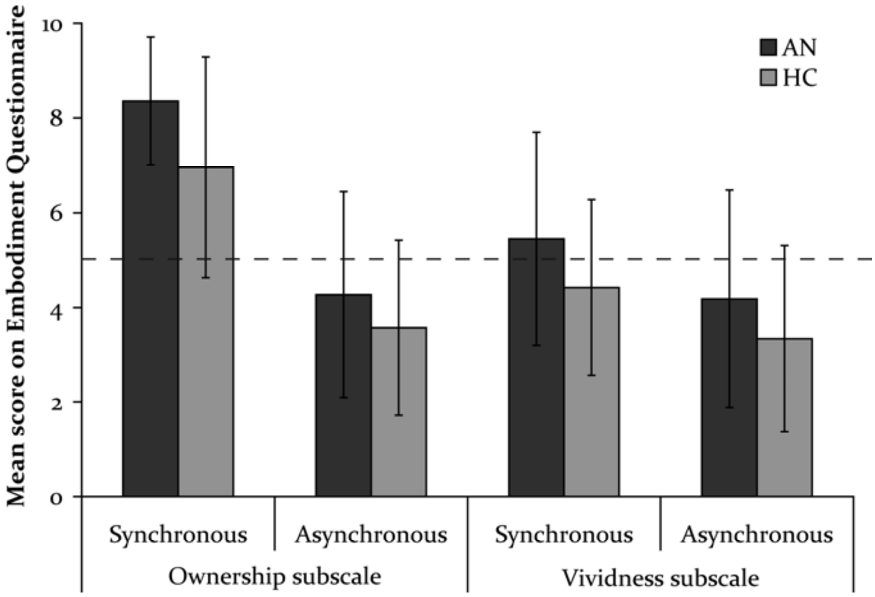


Figure 3. Mean scores on Ownership and Vividness subscales of the Embodiment Questionnaire (EQ) by condition and group. Error bars depict the SD. The dashed line at "5" depicts neutral response, i.e. responses above "5" indicate experience of ownership over the rubber hand or a vivid experience of the illusion; responses below "5" indicate no experience of ownership over the rubber hand or no vivid experience of the illusion.

3.3. Size estimation

3.3.1. Actual size and general performance on hand size estimation

First, Bonferroni corrected independent samples t-tests (critical $p=.0125$) showed that AN patients and HC did not differ on actual hand width, $t(54)=-1.15$, $p=.256$; wrist width, $t(54)=0.25$, $p=.807$ and length of own hand, $t(43.31)=-1.72$, $p=.091$. Bonferroni corrected one sample t-tests (critical $p=.0125$) showed that for AN patients own wrist width was larger than wrist width of the rubber hand, $t(27)=-5.25$, $p<.001$. No differences were found regarding hand width, $t(27)=1.47$, $p=.152$, and hand length, $t(27)=1.23$, $p=.230$. For HC wrist width, $t(27)=5.67$, $p=<.001$, and length of own hand, t(27)=5.54, p<.001 were larger than wrist width and length of the rubber hand. No differences were found regarding hand width, t(27)=2.61, p=.015.

Second, Bonferroni corrected one sample t-tests (critical p=.0125) showed that before the RHI was induced AN patients overestimated own hand width, t(27)=-3.01, p=.006, and own wrist width, t(27)=-3.68, p=.001, but not own hand length, t(27)=-1.04, p=.308. HC correctly estimated own hand width, t(27)=-0.49, p=.625, wrist width, t(27)=-1.29, p=.207, and hand length, t(27)=0.38, p=.707.

Third, Bonferroni corrected one sample t-tests (critical p=.0125) showed that before induction of the RHI, AN patients correctly estimated hand width, t(27)=1.46, p=.157, wrist width, t(27)=-2.66, p=.013 and length of the rubber hand, t(27)=-1.97, p=.059. Similarly, HC correctly estimated hand width, t(27)=0.23, p=.817, wrist width, t(27)=-1.53, p=.138, and length, t(27)=-2.39, p=.024 of the rubber hand.

Taken together, in terms of width the rubber hand was equal to actual hand width of both AN patients and HC. AN patients and HC did not differ in actual hand size. AN patients overestimated the width of their own hand and wrist, but correctly estimated the length of their own hand. HC correctly estimated all parts of their own hand. Both AN patients and HC correctly estimated the width, width of the wrist and length of the rubber hand. For the absolute values of hand size and hand size estimation, see Table 2.

Table 2. Actual dimensions of the rubber hand and hands of participants, and size estimations (before RHI induction) of the rubber and actual hand by group (in mm).

	AN (n=28)				HC (n=28)			
	Rubber hand		Own hand		Rubber hand		Own hand	
	M	SD	M	SD	M	SD	M	SD
Actual dimensions								
Width	71.09	0.00	72.00	3.27	71.09	0.00	73.15	4.19
Wrist	49.10	0.00	51.79	2.28	49.10	0.00	51.62	2.35
Length	87.33	0.00	89.05	7.41	87.33	0.00	91.83	4.30
Size estimation								
Width	69.35	6.80	77.23	8.47	71.24	5.88	73.71	7.48
Wrist	52.81	6.95	56.25	6.89	50.70	4.75	52.83	5.02
Length	90.21	8.15	91.10	6.39	91.83	11.50	91.14	11.37

3.3.2. Size estimation and the Rubber Hand Illusion

We calculated difference scores by subtracting the size estimation made after the induction of the RHI from the size estimation made before induction of the RHI (see Table 3). Note that positive values indicate an increase in size estimation after induction of the RHI, and negative values a decrease in size estimation.

Table 3. Difference in size estimation before and after induction of the RHI in mm for the rubber hand and own hand, by group and condition (critical p=.0025).

	AN (n=28)				HC (n=28)			
	M	SD	t (df=27)	p	M	SD	t (df=27)	p
Rubber Hand								
Synchronous condition								
Width	2.68	5.89	2.41	.023	1.92	5.57	1.82	.080
Wrist	2.42	4.34	2.95	.006	2.03	4.52	2.37	.025
Length	0.61	8.40	0.38	.705	-1.67	8.35	-1.06	.299
Asynchronous condition								
Width	1.95	6.87	1.15	.145	-0.64	4.49	-0.75	.458
Wrist	2.13	5.98	1.89	.070	1.33	3.33	2.11	.044
Length	-0.67	10.89	-0.32	.749	-3.10	8.85	-1.85	.075
Own Hand								
Synchronous condition								
Width	-7.85	5.19	-8.01	.000	-2.51	5.17	-2.57	.016
Wrist	-1.41	4.72	-1.58	.126	0.59	6.64	0.86	.398
Length	-2.01	5.94	-1.79	.085	-0.65	5.51	-0.62	.540
Asynchronous condition								
Width	-6.70	6.95	-5.10	.000	-2.22	4.58	-2.56	.016
Wrist	-1.26	4.84	-1.37	.181	-0.33	3.54	-0.49	.627
Length	-2.73	6.95	-2.08	.047	-2.77	5.81	-2.52	.018

First we compared the difference scores to zero in a Bonferroni corrected one sample t-test (critical p=.0025) for each group (AN and HC) and each part of the hand (width, wrist, length), in order to see for which hand parts size estimations significantly changed after the RHI was induced. Two differences scores significantly differed from zero. AN patients estimated own hand width in both the synchronous (M=-7.85 mm, SD=5.19, t(27)=8.01, p<.001) and asynchronous condition (M=6.70, SD=6.95, $t(27)=5.10$, $p<.001$) as smaller after induction of the RHI (see Table 3). These two difference scores did not significantly differ from each other, $t(27)=-0.85$, $p=.401$.

Second, for AN patients' own hand width, we tested whether the size estimation (absolute values) made after induction of the RHI differed from the actual size of their of the hand. The results of the paired samples t-test indicated no significant difference in both the synchronous and asynchronous condition, $t_{synchronous}(27)=1.47$, $p=.152$; $t_{asynchronous}(27)=0.74$, $p=.466$. Note that before induction of the RHI, AN patients' size estimation for own hand width *did* differ from actual hand width $t(27)=-3.01$, $p=.006$. In addition, another paired samples t-test indicated that AN patients post estimation of own hand width was not significantly different from hand width of the rubber hand, $t_{synchrounous}(27)=0.97$; $t_{asynchrounous}(27)=0.29$.

3.3.3. Correlation between size estimation and RHI measures

For the AN and HC group separately we performed Bonferroni corrected Pearson's correlations (critical p=.001) investigating the association between subjective RHI measures (i.e. EQ Ownership and EQ Vividness), perceptual RHI measures (i.e. proprioceptive drift), pleasantness ratings of tactile stimulation, and hand size estimation. We did not find significant correlations between any of the variables, except for a few which did not lend themselves for further interpretation.

4. Discussion

Recent studies indicate multimodal body representation disturbances in AN (e.g. Case et al., 2012; Guardia et al., 2012b; Keizer et al., 2013; Keizer et al., 2012). Inducing bodily illusions, such as the RHI, enables a deeper understanding of this disturbed experience of the body, specifically the plasticity of body representations. Here we induced the RHI in a group of AN patients and healthy females. Second we investigated the possible influence of induction of the RHI on body (hand) size estimation.

4.1. Enhance effect of the Rubber Hand Illusion on body ownership

The results showed a stronger subjective experience of the RHI in AN patients compared to healthy females, which replicates previous findings by Eshkevari and colleagues (2012). AN patients showed higher levels of experiencing ownership over the rubber hand and vividness of the illusion than healthy females in the synchronous as well as the asynchronous (control) condition. Note that in the asynchronous condition AN patients still rated statements on average as below "neutral", and thus did not experience the illusion (i.e. ownership over the rubber hand) during asynchronous stroking. Alternatively, AN patients' higher ratings on the ownership and vividness statements might, to some extent, reflect a general tendency of AN patients to respond affirmatively. However, such a tendency was not observed in ratings of pleasantness of tactile stimulation during the illusion.

Overall, proprioceptive drift was larger in the synchronous than asynchronous (control) condition, but in contrast to findings by Eshkevari and colleagues (2012), it was not significantly larger in AN patients compared to HC. Inability to replicate the results found by Eshkevari and colleagues (2012) regarding proprioceptive drift may be due to a power issue. Eshkevari and colleagues had a larger sample size (78 AN patients), while our sample size might not have been big enough to detect significant differences between the groups. It should however be noted that some researchers argue that experiencing ownership over the rubber hand does not automatically lead to an update in the perceived spatial location of the own hand (e.g. Longo et al., 2008; Rohde et al., 2011). For example Rohde and colleagues (2011) suggest that the experience of ownership relies on visuotactile integration, whereas proprioceptive drift involves a distinct mechanism, visuoproprioceptive integration (Rohde et al., 2011). Our results confirm this proposed dissociation between ownership and drift. Here AN patients show abnormal (enhanced) experience of rubber hand ownership, while their felt position of the hand appears to be similar to healthy controls. In addition, we did not find a correlation between ownership and proprioceptive drift in either group.

Experiencing ownership over a rubber hand during the RHI has been interpreted as signaling a change in the representation of the body: A fake rubber hand replaces the own hand in the experience of the participant (e.g. Longo et al., 2009; Moseley et al., 2008a). This is supposedly the result of multisensory integration in which vision of stroking on the rubber hand is dominant and captures the tactile sensation on the participant's actual hand (Botvinick and Cohen, 1998). The strength of the illusion, however, is reduced by for example anatomical and postural discrepancies between the visible, fake, stimulated body part and the stimulated, actual, body part occluded from view (e.g. Costantini and Haggard, 2007; Tsakiris and Haggard, 2005). It has therefore been suggested that the illusion of ownership is also modulated by internal models of the body, which interact with visuotactile input (Tsakiris, 2010). A stronger experience of ownership during the

RHI in the AN group implies that they more readily accept inaccurate bodily information (rubber hand) to be valid (it is my hand) after comparing visual and postural aspects of the rubber hand to internal models of the body. In other words, it appears that AN patients assign more weight to external visual input compared to stored and online internal bodily information, rendering the representation of their body more malleable. In a previous study with healthy participants Tsakiris and colleagues (2011) posited that reduced interoceptive awareness may be responsible for such a process. Interestingly, AN patients show deficits in interoceptive awareness (Pollatos et al., 2008). Interoceptive awareness has not only been linked to body awareness and ownership, but has been implicated as crucial in all bodily feelings (see e.g. Craig, 2009). Thus, in a broader sense, distorted weighting of interoceptive and exteroceptive sensory signals in forming a coherent representation of the body may not only result in more easily accepting a rubber hand as one's own. Possibly, excessive focus on exteroceptive input may also play a role in AN patients' disturbed experience of body size. This may be analogous to findings in healthy participants, who in absence of internal signals (e.g. due to anesthesia) experience an increase in size and weight of the affected body part (see e.g. Gandevia and Phegan, 1999).

Note however that supposed reduced interoceptive awareness in AN patients would also predict larger proprioceptive drift in this group (see e.g. Tsakiris et al., 2011). Nevertheless, the differential effect for the subjective (i.e. ownership over rubber hand) and perceptual (i.e. proprioceptive drift) experience of the RHI found here may not be particularly surprising. To put it simply, the subjective experience of the RHI taps into "what"-aspects of the body (is this my hand?), while the perceptual assessment of the RHI taps into "where"-aspects of the body (where is my hand located?). From previous studies it has become clear AN patients have difficulty identifying "what" their body is, specifically in terms of size of the body (e.g. Skrzypek et al., 2001) but there is no reason to assume that they also show difficulty in identifying "where" their body is (Keizer et al., 2013).

4.2. Size estimation and the Rubber Hand Illusion

First, and as expected, before induction of the RHI, both AN patients and healthy females correctly estimated the size of the rubber hand. Healthy females also correctly estimated the size of their own hand, while AN patients overestimated own hand width and wrist width, but not own hand length. This confirms that indeed AN patients do not have a general deficit in size estimation of external objects, but that performance is only altered concerning their own body size (e.g. Slade and Russell, 1973). Here it even appears to be selectively disturbed for width of the body, but not length.

As for hand size estimation, after induction of the RHI, AN patients' size estimations of own hand width was on average 7.85 mm (synchronous condition) and 6.70 mm (asynchronous condition) smaller compared to before induction of the RHI. This post-RHI size estimation was found to be more accurate, i.e. not different from actual hand width, and also not different from hand width of the rubber hand (note that hand width of the rubber hand and actual hand of AN patients did not differ). Thus, the direction of the change is in accordance with what we expected based on Haggard and Jundi's findings (2009). We hypothesized that the size of the rubber hand would be incorporated into the body representation, and that participants would evaluate own hand size as equal to rubber hand size following synchronous RHI induction. This hypothesis was partly confirmed. However, following this hypothesis, our results should also have shown a decrease in size estimation of own wrist width after synchronous induction in the AN group and wrist width and hand length in the healthy control group.

What is particularly interesting is that our results showed changes in size estimations of own hand width in the AN group after both the synchronous and asynchronous (control) condition of the RHI. In other words, changed size judgments appear to be unaffected by the illusion, i.e. the experience of ownership over the rubber hand, as in the asynchronous (control) condition patients did not report this experience of ownership. Another remarkable finding is that AN patients showed a selective decrease in size estimation for own hand width. After induction of the RHI AN patients' no longer overestimated the width of their hand, but size estimations for their wrist did not change, implying that both before and after induction of the RHI wrist width was overestimated.

We offer two possible explanations for the found results. First, during the induction of the RHI participants were instructed to focus their attention on the rubber hand lying in front of them. In both the synchronous and asynchronous condition participants received tactile input on mainly the index finger, middle finger and back of the hand, the wrist was not stimulated at all. Thus, the wrist might have attracted less attention and therefore the reduction in size perception only applied to hand width. Related to this, it could be that simply having access to visual information about the rubber hand has resulted in changed size estimations in the AN group. Consequently, this would imply that AN patients did not make a size estimation based on an internal model of their own hand size, but based on the size of the rubber hand lying in front of them. This would imply that simply visually exposing AN patients to a rubber hand placed in an anatomically congruent position would be sufficient for this effect to occur. In future studies these explanations can be verified.

4.3. Conclusion and clinical implications

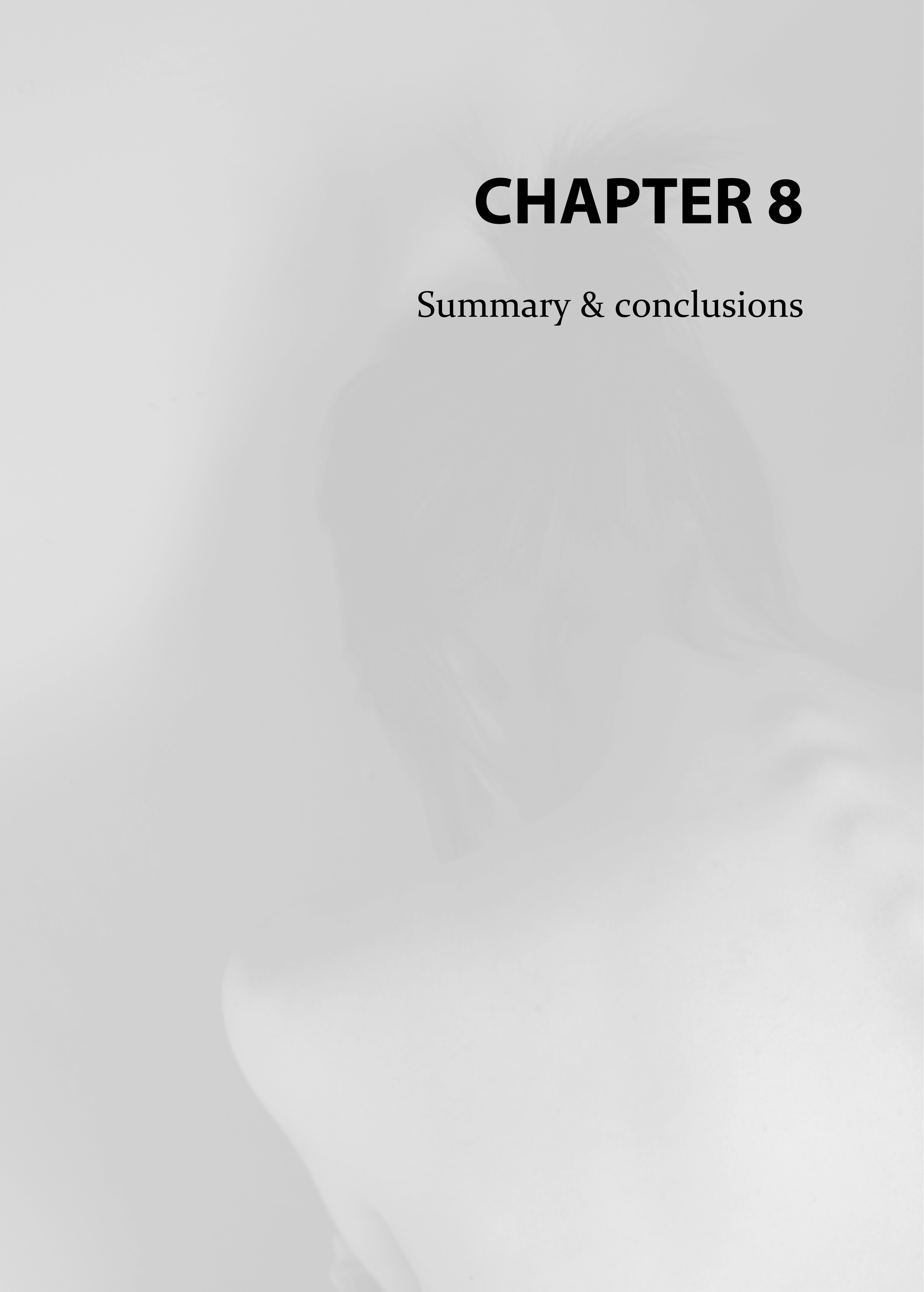
The present experiment shows two main findings. First, AN patients had a stronger experience of ownership over the rubber hand in the RHI than healthy females, in both the synchronous and asynchronous (control) condition. Thus, AN patients appear to have a more malleable body representation and more easily integrate a rubber hand into their body representation, most likely due to prioritizing external sensory input over interoceptive signals. AN patients however did not show larger proprioceptive drift than healthy females. Second, after induction of the RHI, only AN patients' size estimations for own hand width changed (decreased) in both the synchronous and asynchronous condition. AN patients showed no changes in size estimation of wrist width and hand length, healthy females showed no changes in size estimation for any part of the hand.

Our findings offer important insights for clinical practice. Increased malleability of body representation as found in the present study implies that AN patients' body representation is susceptible to change. Indeed, one of the general characteristics of AN is that they experience their body size different (bigger) than it actually is. What is particularly interesting about the present study is that the change in body representation brought about here was not directly related to eating disorder pathology, but rather related to a relatively neutral body part (hand). AN patients in the current study even estimated their hand size more realistically after (a)synchronous induction of the RHI. We thus showed that it is possible to change AN patients' body representation/experience of body size, even if it does not confirm their anorectic cognitions (my body is fat). This is also what treatment of AN aims to do: Changing body representations so that they no longer are distorted in the direction of fatness. However, these treatments, which focus mostly on providing direct visual information (e.g. via mirror) and cognitive behavioural techniques, are often unsuccessful in inducing such a change (Exterkate et al., 2009). What is it then about the present experiment that has resulted in a successfully changed experience of body size? It does not seem to be related to multisensory integration, as size estimation of the hand became smaller in the AN group in both the synchronous and asynchronous (control) condition of the RHI. In the latter, no multisensory integration took place. It might be related to another aspect of the RHI paradigm. In both the synchronous and asynchronous condition participants did not have access to visual information of their actual hand, while they did receive tactile input on their actual hand. Even though the specific underlying mechanisms cannot be revealed by the current results, the size estimation findings point in the direction of focusing less on providing visual information of the own body during treatment and more on external providing multisensory input when attempting to change the experience of body size.

That we identified differences in both the experience of ownership over the rubber hand, and size estimation of the hand between AN patients and HC underlines the severity of body representation disturbances in AN. Compared to body parts such as the abdomen, hips, or thighs, the hand is a relatively neutral body part, for which patients exert relatively less concerns in terms of fatness. Future studies might focus on bodily illusions for body parts that are more salient for eating disorder patients, or whole body illusions (e.g. Ehrsson, 2007). This would give insight into whether our findings extend to different parts of the body, and enhance clinical applicability of the results.

CHAPTER 8

Summary & conclusions



1.1. Background

One of the central symptoms of AN is a disturbance in how body weight and shape are experienced. AN patients are underweight, but have a persistent perception and experience of their own body as bigger than it objectively is (APA, 2000). Interpretation of traditional research on this topic (for reviews see e.g. Cash and Deagle, 1997; Farrell et al., 2005; Skrzypek et al., 2001; Smeets, 1997), mainly conducted by clinical psychologists and psychiatrists, is complicated by two main problems. First, the methodological paradigms (BSE tasks) that were used were inspired by perceptual psychology and psychophysics. In relation to this, perceptual representations of the body were regarded as similar to perceptual representations of objects. However, body representations as opposed to object representations do not form a neutral, static, percept or representation but are heavily influenced by emotions and attitudes. A second complicating factor is that most traditional body image research has focused on visual perception of the body and its size, rendering influences from other senses, such as touch, irrelevant.

In this thesis we approached the disturbed experience of body size from a theoretically and methodologically different perspective rooted in neuropsychology and cognitive neuroscience. This approach takes into account that 1) representations of the body are special, and fundamentally different from (neutral) object representations, and 2) that perception and experience of the body is rooted in a multisensory context. According to neuropsychological/cognitive neuroscientific views, body representations contain abstract, multimodal, bodily dimensions stored in a network of parietal, frontal and insular cortical areas (see e.g. de Vignemont, 2010; Dijkerman and de Haan, 2007; Gallagher, 2005; Haggard and Wolpert, 2005; Paillard, 1999; Serino and Haggard, 2010). Different body representations can be distinguished. For example, the body image, which is mainly involved in conscious body-related perception and cognition, and the body schema, which is mainly involved in relatively unconscious action guidance (see e.g. de Vignemont, 2010; Dijkerman and de Haan, 2007).

Previously it was shown that AN patients, on a behavioural and functional level, show differences compared to controls in terms of multisensory processing of bodily information (e.g. Case et al., 2012; Eshkevari et al., 2012; Grunwald et al., 2001; Guardia et al., 2012b; Mohr et al., 2010; Nico et al., 2010; van Kuyck et al., 2009). However, none of these studies directly focused on whether multimodal metric aspects of body representation are disturbed in AN. We are among the first to directly investigate this adopting a neuropsychological approach.

The main aim of the present thesis was therefore to increase understanding of the disturbed experience of body size in AN, and specifically focusing on metric aspects of the mental representation of the body. The approach adopted here is rooted in neuropsychology and could be considered a paradigm shift. The present thesis consisted of three sections. In this chapter I will first summarize the findings from the studies presented in this thesis on a section by section basis, starting with body image studies, continuing with body schema studies, and ending with findings on plasticity of body representation. Subsequently I will discuss how the findings contribute to a more complete understanding of the nature and extent of the disturbed experience of body size in AN, and address suggestions for future research and clinical implications of the findings.

1.2. Section 1 – body image

Section 1 included three studies that focused on metric aspects of body image. First, in **Chapter 2**, a novel method for assessing metric tactile body representations was presented (based on Anema et al., 2008; Taylor-Clarke et al., 2004). As tactile representations of the body were largely ignored in relation to AN, we developed a method tailored to AN patients to assess a possible disturbance in this domain. To validate this method we tested a group of healthy participants. Specifically, blindfolded participants were asked to estimate the distance between two tactile stimuli presented to their forearm by separating their thumb and index finger. The results showed that healthy participants' performance on this paradigm was robust and unaffected by gender, stimulation-site (left or right arm), or response-hand (left or right hand). In accordance with previous studies (Spitoni et al., 2010), performance did not correlate with performance on a lower level tactile detection task, which indicates that different processes underlie size estimation and simple tactile detection.

The aim of **Chapter 3** was twofold. First, the visual mental representation of body size was assessed. In traditional BSE research the visual mental representation of body size was often assessed using tasks in which the stimuli itself consisted of visual information on body size (e.g. a (distorted) photograph of the body). Especially in the AN group such a priori visual information might bias their subsequent task response, making it an assessment of body attitudes more than the visual mental image of body size (see e.g. Smeets, 1997; Smeets et al., 2009). Here the visual mental image of the body was assessed using a method (based on Smeets et al., 2009) in which stimuli consisted of body-related words instead of body-related images. As such, responses could not be a priori biased by visual information, but required generation of a visual mental image of the body. The results showed that AN patients made more errors in judging their body width, implying that AN patients' spontaneously generated visual mental representation of their body width is more inaccurate than that of healthy females. Second, we investigated tactile body representation disturbances in AN. With a method similar to the one presented in Chapter 2. AN patients were found to overestimate tactile distances on their forearm and abdomen compared to healthy females, but also compared to the actual applied distance, while healthy females underestimated distances. Overestimation of tactile distances in the AN group implies that AN patients process spatial aspects of touch stimuli differently than healthy females. They interpret a tactile distance as bigger than it actually is, i.e. as if a bigger surface of their skin is touched, which may be related to the experience of having a fat body that is characteristic for this clinical group. Most importantly, a disturbance in tactile body representation was identified in AN, implying that modalities other than vision and cognition are affected as well.

In **Chapter 4** we further explored the nature of tactile body representation disturbances in AN. Would overestimation of tactile distances in the AN group result from higher-order deficits, or instead be related to disturbances in lower level somatosensory processing (e.g. input on receptor level)? The results showed that, in accordance with findings from Chapter 3, again, AN patients and healthy females differed in tactile size estimations. However, in Chapter 4 we found an interaction effect between group and body part on which tactile stimuli were presented, indicating that the difference in size estimation between AN patients and healthy females was most pronounced for stimuli presented to the abdomen compared to the forearm. In other words, it appears that AN patients representation of body size is more disturbed for body parts that they worry about frequently, compared to less "sensitive" body parts. We further included two tasks assessing lower level somatosensory perception for which supposedly a body representation is not used (e.g. Spitoni et al., 2010). AN patients showed altered performance compared to healthy females on measures of tactile sensitivity as well as two point discrimination. Specifically, AN patients and HC differed in tactile sensitivity for the abdomen (AN were more sensitive), but not the arm, and overall AN patients showed decreased tactile acuity. Regression analysis showed that tactile distance estimations on the arm were predicted by group membership (either AN or healthy female), and that distance estimations on the abdomen were predicted by group membership and two point discrimination (AN plus low tactile acuity predicted larger size estimations). These findings imply that AN patients tactile body image disturbance is most likely to result from a combination of higher order influences related to AN pathology, as well as lower level somatosensory disturbances.

In relation to the main aims of the present thesis, the findings from Section 1 show that body image disturbances in AN are not limited to distorted visual information processing, but also affect how touch is processed and perceived by this group. Disturbed perception of specifically tactile distance appears to result from deficits in basic somatosensory processing (i.e. tactile input arrives in the brain distorted) as well as higher order influences related general AN pathology (i.e. negative body attitudes and specific attentional processes).

1.3. Section 2 – body schema

From a neuropsychological perspective a distinction between different types of body representations can be made (see e.g. de Vignemont, 2010; Dijkerman and de Haan, 2007). Section 1 focused on multimodal body image, Section 2 includes two chapters that focus on body schema.

First, in **Chapter 5** we presented a methodological study in which a new method for assessing body schema (based on Warren and Whang, 1987) was evaluated in a group of healthy participants. In traditional literature on body size experience in AN, body schema, or how the body is used in action (guidance), is a largely overlooked aspect of body representation, and not investigated. Therefore we developed a method to assess this. Given that body schema is defined as a relatively unconscious representation of the body (e.g. Dijkerman and de Haan, 2007) it is important that body schema is measured whilst participants perform actions relatively automatically, i.e. without focusing conscious attention on the task. Therefore we asked healthy participants to walk through apertures varying in size, either being aware of the purpose of the study (i.e. measuring shoulder rotation when crossing the aperture) or being unaware (i.e. being told that they participated in a haptic memory experiment). We found that both groups started to rotate their shoulders as soon as an aperture was about 1.2 times as wide as their own shoulders. We found a marginally significant difference between the groups in terms of amount of shoulder rotation, with unaware participants making smaller shoulder rotations at the opening width for which they started rotating than aware participants. It thus seems that performing actions without focusing conscious attention on the task increases efficiency of performing the action, but does not influence action-planning.

In **Chapter 6** we investigated body schema disturbances directly in an AN population. Although it was previously assumed that AN patients do not have problems regarding body schema, they do often report that they experience feelings of taking up too much space in a room, or being too big. Could this affect, or result from, how they move around in space? Locomotion in AN was assessed, using an aperture task similar to the one presented in Chapter 5. All participants were unaware of the purpose of the study. The results showed a group difference in terms of the opening width for which participants started rotating in order to fit through. Healthy females rotated their shoulders as soon as an opening was 1.25 times their shoulder width, or smaller, replicating the findings from Chapter 5. However, AN patients already started rotating as soon as the opening was 1.40 times as wide as their own shoulders. No other relevant differences on measures of locomotion were found between the groups (e.g. onset of rotation, amount of rotation). Interestingly, we found that AN patients and healthy females no longer differed in critical aperture as soon as this was calculated using their estimated shoulder size divided by the opening width for which they started rotating, compared to their actual shoulder width. This implies that AN patients' body schema is disturbed and that they unconsciously engage in whole-body actions and locomotion on basis of an enlarged internal modal of body size.

The main aim of the present thesis was deepening insight in the disturbed experience of body size in AN. Taken together the findings from Section 2 show for the first time that body representation disturbances in AN extend to the body schema. AN patients move around in space as if their body is bigger than it actually is, without being aware of doing so. In other words, their actions are, relatively unconsciously, guided by a representation of body size that is bigger than their body actually is.

1.4. Section 3 – plasticity of body representation

Section 1 and 2 focused on body image and body schema respectively. Both were found to be disturbed in AN. A next logical step would be assessing whether this enlarged representation of body size can be changed. Therefore, we address the plasticity of body representation in AN in Section 3, with a specific focus on metrics, i.e. on how the body is experienced in terms of size and whether this can be changed.

In **Chapter 7** we assessed changeability of body representation in AN. A method rooted in cognitive neuroscience to assess malleability of body representation is the Rubber Hand Illusion (RHI, see e.g. Botvinick and Cohen, 1998). This method is particularly interesting in an AN group, as during the illusion a fake rubber hand is experienced as belonging to the own body. AN patients show no deficits when estimating the size of objects, but they do estimate their own body size in a disturbed way. We adapted traditional the traditional RHI method by including a size estimation of the rubber hand and own hand before and after induction of the illusion. This helps determining whether AN patients estimate an object (rubber hand) differently once it becomes incorporated in their body representation (i.e. after induction of the illusion). The results first showed that AN patients have a stronger experience of ownership over the rubber hand than healthy females, implying increased malleability of body representation. Interestingly, AN patients size estimations of their *own* hand, but not the rubber hand, changed after induction of the rubber hand illusion. After both the experimental and control condition of the RHI AN patients estimated the size of their hand as more accurate, and no longer showed overestimation of own hand size. It thus appears that the advantage of estimating the size of an external objects transfers to estimating the size of the own body. This transfer seems to be unrelated to experiencing ownership over the rubber hand. Although the exact mechanisms behind a change in body size estimation in the AN group cannot be inferred from the present results, they do indicate that body representation distortions in AN are not static, but *can* be corrected.

1.5. What do the findings tell us?

At the beginning of this chapter two main problems with traditional BSE research were addressed. First, traditionally body percepts/representations were not regarded as different from neutral object percepts/representations. Second, there was an almost exclusive focus on how body size perception/representation in the visual domain. In the present thesis the disturbed experience of body size in AN was investigated using an approach rooted in neuropsychology, taking the previously mentioned problems into account. In short, the most important conclusions from the studies presented in this thesis are that:

- a paradigm shift allowed for testing of new hypotheses related to the disturbed experience of body size in AN;
- body representation disturbances in AN are more severe and widespread than previously assumed;
- AN patients have an inaccurate visual mental representation of body size;
- AN patients process and perceive tactile information differently (bigger) than healthy females;
- AN patients perform actions based on an enlarged internal representation of body size;
- AN patients' disturbed experience of body size can be changed.

1.6. Body representations in AN – a revisited perspective

The results from the present thesis have deepened and broadened the understanding of the disturbed experience of body size in AN. A paradigm shift enabled testing of previously unaddressed hypotheses, which in turn has resulted in novel perspectives on body representation disturbances in AN. Although it was traditionally assumed that AN patients merely thought of their bodies as fat, and visually perceived them as such, we have shown here that the disturbance in body size experience in AN extends beyond the visual and cognitive modality. Specifically, *multimodal* body image disturbances have been identified, including a disturbance in processing of tactile input, as well as body schema disturbances. These new insights imply that the disturbed experience of body size in AN is more severe than was previously thought. This has interesting implications for theory on body representation disturbances in AN, as well as for treatment of this disturbance.

1.6.1. Theoretical implications

Figure 1 depicts the traditional perspective on body representation disturbance in AN (left) as well as the revisited perspective based on the results of the studies described in the present thesis (right). According to the traditional perspective, two representations of the body were involved in the disturbed experience of body size in AN, an affective body representation (body attitudes) and a perceptual body representation (body image). It was generally thought that these two representations were independent from each other, and that the main problem concerned a top-down influence of negative body attitudes (e.g. thinking that the body is fat) on visual representations of the body (defined as body image, see e.g. Smeets, 1995). Body schema was acknowledged as an existing construct, but it was assumed to be irrelevant to the disturbed experience of body size in AN. Adopting a different point of view, rooted in cognitive neuroscience, in the present thesis, led to the formulation of novel hypotheses and methods. Testing of these hypotheses provided new insights into the disturbed representation of body size in AN. As depicted in the revisited perspective (Figure 1, right) we propose that body representation disturbances in AN should be regarded as multimodal, including distortions at the level of body image (visual, tactile, and affective modality) as well as body schema (action guidance/performance).

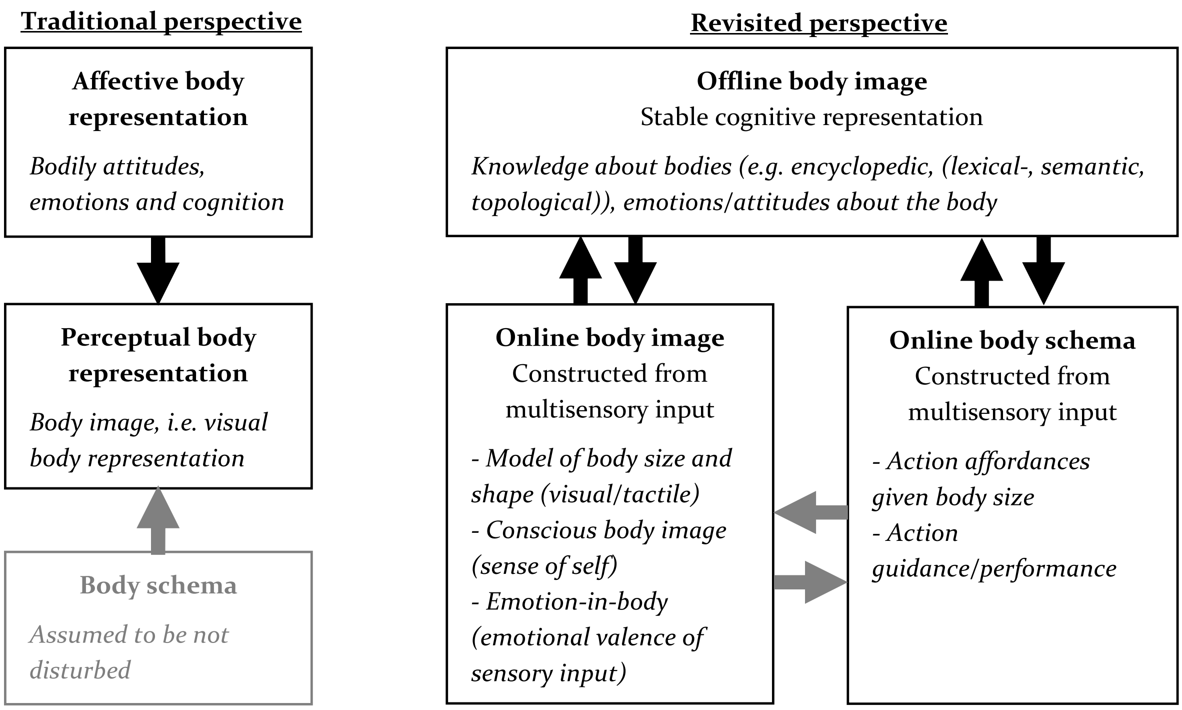


Figure 1. Traditional versus revisited perspective on body representation disturbances in AN.

A first important difference is that the new perspective includes the concept body schema. From traditional literature we may infer that the shared opinion seemed to be that body schema was not of relevance to the disturbed experience of body size in AN (Figure 1, left, in grey). In other words, it was assumed that with regard to performing actions, AN patients showed no disturbances. Results from the present thesis however show that the disturbed experience of body size in AN patients also affects how they move in space, rendering the inclusion of body schema disturbances appropriate.

A second difference between the traditional and revisited perspective is the role that is ascribed to higher order affective/emotional bodily information in the disturbed experience of body size in AN. In the traditional perspective bodily emotions supposedly had an unidirectional influence on how the body was (visually) perceived (e.g. Smeets, 1995). In contrast, here we propose that AN patients' emotions related to the body are strongly entwined with, and interact with the online body image and body schema. According to theories rooted in cognitive neuroscience the online body image and body schema are invoked during processing of (multi)sensory input to construct representations of the body that reflect the present state the body is in (e.g. Longo et al., 2010). The online body image is supposedly related to conscious bodily perception, and the online body schema aids unconscious bodily actions (e.g. de Vignemont, 2010; Dijkerman and de Haan, 2007; Longo et al., 2010). Both representations of the body can be further divided into "sub-representations" that each have their own specific function (see Figure 1, right). Note however that the lists of sub-representations in Figure 1 (right) are not exhaustive (e.g. de Vignemont, 2010; Dijkerman and de Haan, 2007; Longo et al., 2010), only the sub-representations relevant to the present thesis (i.e. relevant to distorted experience of body size in AN) are included here. The online body image for example includes sub-representations that allow for the construction of an internal model of the shape and size of the body, as well as a so-called conscious body image, which is important in maintaining a coherent sense of self. Importantly, the online body image also includes an emotional component, which is related to the emotional valence that is ascribed to sensory input. When a healthy individual for example perceives touch on their body, they are almost instantly able assign emotional valence to what they perceive. As such body related perception and body related emotional information are suggested to be strongly linked, most likely due to connections between brain areas important in (higher order) processing of sensory input (here, e.g. secondary somatosensory area (SII)) and the insula, see e.g. Dijkerman and de Haan, 2007). In addition it is quite adaptive that a strong link between bodily perception and the associated affective state of the body exists, as it helps to avoid unpleasant, or even harmful, stimuli.

As the body schema is a mainly unconscious representation of the body, it does not include an emotional component. However, it is suggested that it can be influenced by affective/emotional information about the body stored in the offline body image (e.g. de Vignemont, 2010; Longo et al., 2010). We believe that especially in AN patients it is highly likely that higher order emotional aspects of body representation as stored in the offline body image exert an influence on how the body is perceived and used in action. What is important about AN pathology is that the experience of body size and the appearance of the body take up a central role in the disorder (APA, 2000). As such, all input that is body-related is likely to be heavily laden with emotions/attitudes in this group. AN patients are overly aware of their body and have an excessive focus on body-related information (see e.g. Lee and Shafran, 2004; Shafran et al., 2007; Smeets et al., 2008). I believe it is therefore virtually impossible to separate for example an emotional evaluation of the body or body related attitudes from how sensory input is processed and used in AN patients.

The emotional evaluation of the body in AN might serve as a maintaining factor of disturbed experience of body size. On the one hand emotional aspects of offline body representation are very negative in AN, which can influence bodily perception and action. On the other hand, the emotional component of the offline body representation is based upon general evaluations of appearance, for example by comparing own body size to body size of someone else. In order to make such a comparison, information on own body size is required. Internal models of body size are is stored in the online body image and body schema. Indirectly, information on own body size is thus inferred from how body related sensory input is processed (e.g. how the body is perceived in terms of size (online body image) or how the body is used in action (online body schema)). In other words, as long as AN patients process body related sensory input in a disturbed way (e.g. perceive touch to their skin as enlarged), a distorted (enlarged) internal model of body size will affect the outcome of emotional evaluations stored in the offline body image, resulting in a negative downward spiral.

Third, in contrast to the traditional perspective, the revisited perspective is multimodal. It includes disturbances of body representation at the level of visual and tactile perception, attitudes/emotions, as well as guidance and performance of actions. The disturbed representation of body size in AN is thus viewed as a distortion that affects multiple modalities in conscious body-related perception as well as relatively unconscious body-related action.

A multimodal perspective on body representation disturbance in AN has two main advantages. A first advantage is that it takes into account that representations of the body are fundamentally different from object representations. Generally, object representations are constructed from external information. That information is not by definition only visual, as individuals for example can manually explore an object. However, an important difference in constructing object representations and body representations is that for object representations the actor and the object are independent from each other: The actor gathers external input about the object. In contrast, body representations are constructed from external as well as internal input: The body can serve as both the actor and the object. For example, when constructing a representation of a bunny an individual has access to visual input and perhaps tactile input, but when constructing a representation of the own body the individual also has access to internally generated input (i.e. interoceptive perception), such as proprioception, or emotions and has a sense of ownership/agency. In case of the former the actor is unaware of the internal physical state of object (the bunny), while in case of the latter, the actor does have this information, as it concerns his/her own body. The new perspective does not only include input from visual perception, but also touch related input, emotional input, and action-related input, taking into account that representations of the own body are based on different input compared to object representations.

A second advantage of a multimodal perspective on the disturbed experience of body size in AN is that it more accurately matches clinical observations, and patients' own experience of their disturbed experience of body size (Espeset et al., 2011). Patients themselves indicate that feeling fat is in their experience not limited to how they think about their body or how they visually perceive it, but that it rather is something that they feel from their body. In addition patients note that the feeling of having a big body can persist, even though treatment has resulted in more accurate visual perception of their body and more positive bodily cognitions.

A fourth difference between the traditional and revisited perspective is that the new perspective includes a possible (Figure 1, right, in grey) interaction between body image and body schema. In the traditional perspective this interaction is absent. This is mainly related to the general assumption that body schema would not be disturbed in AN. In neuropsychology the dominant view exists that body image and body schema are dissociated from each other (see e.g. Dijkerman and de Haan, 2007; Gallagher, 2005; Head and Holmes, 1911; Paillard, 1999), however there are also some researchers that suggest an interplay between the two (see e.g. de Vignemont, 2010; Longo et al., 2010). Although it is beyond the scope of this thesis so resolve the ongoing debate on the body image – body schema dissociation, it should be noted that although different representations of the body may exist and serve different functions, they might not necessarily operate in strict independence from each other. For example, in one study a bodily illusion was induced in healthy participants. The illusion affected perceptual responses (judgment of location of the body, body image), but not motor responses (reaching movement, body schema, Kammers et al., 2009). However, in another study, using the same bodily illusion but a slightly different motor response (grasping movement), it was shown that now the motor response *was* affected by the illusion (Kammers et al., 2010). These results indicate that in certain tasks the body image and body schema appear to interact. In other words, the interaction between body image and body schema might be dependent upon the function that either representation in a given situation has. It is possible that some aspects of the online body image and body schema are more likely to interact than others.

Following this line of reasoning, the present thesis also suggests an interaction between body image and body schema in AN. The focus was specifically on actions in which the size of the body plays a central role. For such actions an internal model of the size of the body is required, which is assumed to be stored in the online body image (see Figure 1, right, Longo et al., 2010). Therefore, it is plausible that in the light of AN pathology the online body image and body schema interact in certain contexts. Nevertheless, in the current thesis we have found little evidence for a direct association between body image and body schema measures. This absence of significant correlations between the two constructs might however have resulted from a power issue. Sample sizes were big enough to detect changes on separate tasks between AN patients and healthy females, however they might have been too small to be able to detect a correlation between body image and body schema within either group.

Taken together, AN patients are at first glance different from the neuro(psycho)logical (lesion) patients and healthy participants on which body representations theories in cognitive neuroscience and neuropsychology have been built. For example, AN patients suffer from a psychiatric disorder that is likely to affect brain functioning, but they do not suffer from acquired brain lesions that are observed in e.g. stroke patients. Furthermore, AN patients show disturbances on perceptual as well as action related tasks, while in studies on lesion patients double dissociations between e.g. perception and action are of specific interest. Nevertheless these theories have shown to provide a useful basis from which the disturbed experience of body size in AN can be investigated, as well as be placed in a theoretical framework. As indicated earlier, the body representations as specified in Figure 1 (right) are not exhaustive. Future studies in the field of body representation disturbances in AN can take advantage of the large body of literature from cognitive neuroscience and neuropsychology, to explore other (sub)representations of the body in the brain that may be affected in AN.

1.6.2 Clinical implications

Given that disturbed experience of body size has been linked to relapse and unfavorable prognosis in AN (see e.g. Farrell and Shafran, 2006; Freeman et al., 1985; Killen et al., 1996), it is important that treatment approaches are developed that successfully improve body size experience. Moreover, the present thesis has shown that body representation disturbances in AN are not limited to cognitions and visual perception of the body. These new insights should also be taken into account during treatment, so that the full spectrum of body representation disturbances is addressed.

In current treatment of AN pathology there is usually a specific focus on the disturbed experience of body size, for example during psychomotor therapy. What is mainly addressed are cognitions in relation to body size and the visual experience of body size. Research has shown that such approaches are not highly effective in reducing the experience of having a big body (Exterkate et al., 2009). This is also apparent from clinical observations (Espeset et al., 2011). Patients approaching the end of their treatment, who have attained a healthy weight and eating pattern, still indicate that they continue to experience feelings of fatness. They report that during treatment they have learned cognitively that they are not fat, and have developed strategies that help them deal with such feelings. However, most patients indicate that the strong sense of having a (too) big body remains. It thus seems that therapeutic interventions are successful in helping AN patients *cope* with feeling big, but are unsuccessful in actually changing the internal representation of body size stored in their brain. Perhaps the revisited view on body representation disturbances in AN offers possibilities for designing novel therapeutic interventions.

An example of a new treatment approach that follows directly from the research presented in this thesis is related to how participants use their body in action, and the possible beneficial effects of intervening on the level of the body in action. What seems to be important for changing AN patients' vast conviction as well as experience of being bigger than they actually are is receiving undeniable evidence on their true body size and directly experience their actual body size. In Chapter 6 AN patients were found to already rotate their body for an opening that they could objectively walk straight through without bumping in to the sides of the aperture. Generalizing these findings, it could be that AN patients lack direct feedback on their true body size, as they behave and move around as if they are bigger than their actual body dimensions. The brain thus never receives the signal that it is guiding actions wrong, with a too big margin in terms of space. An example illustrating the opposite effect is that pregnant females learn their new, bigger, body dimensions through experience: As their belly grows they often start bumping in to things. Such direct feedback signals the brain that the mental representation of body (belly) size should be adjusted to avoid collisions in the future. For AN patients the opposite happens: They rarely bump in to things and thus do not receive feedback that can facilitate a change in the abstract representation of body size in the brain. Thus, while pregnant women need to incorporate their new, bigger, body size into the mental representation of their body, AN patients should "excorperate" excessive, and non-existent, body volume from their body representation. In AN patients it may therefore be important to offer a treatment approach in which they *do* receive direct feedback on their body size. This might be beneficial for two reasons. First, the brain receives feedback on actual body dimensions and can adjust the mental representation of body size accordingly. Second, due to feedback on actual body size patients will consciously experience that they are smaller than how they usually experience their own body. For example, they might profit from being able to navigate their body through a small space, even though they would not have thought this to be possible when looking at the space beforehand. In treatment exercises involving for example drawing the own body and comparing it to actual body size, patients only see a difference, but do not actually *experience* that they are indeed smaller than their drawing. During the latter exercise it may be relatively easy to deny (the impact of) the difference in estimated and actual body size. However when patients actively performs actions that, according to them, should be impossible given their body size, there is no way to refute the evidence of their actual, small, body dimensions.

Summary in Dutch
Samenvatting in het Nederlands

1.1.Wat is anorexia nervosa?

Anorexia nervosa (AN) is een eetstoornis die bij veel mensen bekend is, ondanks dat deze minder vaak voorkomt dan andere eetstoornissen, zoals boulimia nervosa (BN) en binge eating disorder (BED). AN treft ongeveer 0,6% van de jonge vrouwen, terwijl BN en BED een prevalentie van respectievelijk 2,6 en 3,0% hebben. Toch krijgt AN meer aandacht dan andere eetstoornissen, mogelijk omdat patiënten niet alleen ernstig ziek zijn, maar er ook nog eens sterk vermagerd uitzien. Naast het hebben van (ernstig) ondergewicht en een grote angst om aan te komen, beleven AN patiënten hun eigen lichaamsgewicht en -omvang op een verstoorde manier.

Meestal ontwikkelt AN zich in de (vroege) adolescentie, voornamelijk bij vrouwen. AN is moeilijk te behandelen en ongeveer de helft van de patiënten blijft na behandeling chronisch ziek. Vier tot tien procent van de patiënten overlijdt zelfs aan de gevolgen van AN. Dit maakt dat AN een van de meest ernstige psychiatrische stoornissen is.

Patiënten die lijden aan AN kenmerken zich doordat zij onrealistische doelen stellen ten aanzien van hun lichaamsgewicht. Patiënten streven ernaar zo dun en licht mogelijk te zijn. Om deze doelen te bereiken vertonen patiënten obsessief en ritualistisch gedrag omtrent (niet) eten en bewegen. Het langdurig uithongeren van het eigen lichaam kan resulteren in ernstige lichamelijke klachten, zoals bloedarmoede, hartritme stoornissen, nierfalen, lage lichaamstemperatuur, en botontkalking. Het obsessief bezig zijn met een bepaald eetpatroon en een verzwakte lichamelijke toestand, kunnen er beide toe leiden dat de eetstoornis het leven van de patiënt beheerst. Patiënten kunnen bijvoorbeeld niet meer gemotiveerd zijn of in staat zijn om tijd te investeren in school of werk en sociale relaties of sociale activiteiten.

Dit proefschrift draagt bij aan het beter begrijpen van AN, met een specifieke focus op een van de meest intrigerende symptomen van deze aandoening: De verstoorde beleving van het eigen lichaam. AN patiënten ervaren hun eigen lichaam als groter (dikker) dan het in werkelijkheid is. Gedragsmatig uit de verstoorde lichaamsbeleving zich onder andere in het dragen van verhullende kleding, het vermijden van bepaalde situaties (bijvoorbeeld zwembaden of feestjes), het bekijken of vermijden van het lichaam (bijvoorbeeld in de spiegel) en een sterke behoefte aan sociale feedback over lichaamsomvang. Een verstoorde lichaamsbeleving kan resulteren in beperkt functioneren. Het is bijvoorbeeld niet ongebruikelijk dat patiënten niet naar buiten durven te gaan omdat zij zich te erg schamen voor hun “dikke” lichaam en het anderen niet aan willen doen dit te moeten zien. Het verstoord beleven van het lichaam wordt gezien als een centrale factor in de ontwikkeling en instandhouding van AN en is daarnaast gerelateerd aan behandelsucces en terugval.

Uit onderzoek en de klinische praktijk blijkt dat de verstoorde beleving van lichaamsomvang bij AN hardnekkig is en zelfs na anderszins succesvolle behandeling bij een groot deel van de patiënten blijft bestaan. Dus ondanks dat patiënten na behandeling weer een gezond gewicht en eetpatroon hebben, blijven ze hun lichaam ervaren als dikker dan het in werkelijkheid is. Behandelingen die specifiek ingaan op lichaamsbeleving bij AN richten zich voornamelijk op hoe patiënten over hun lichaam *denken* (cognitie) en hoe ze hun lichaam *zien* (visuele waarneming). Echter, patiënten geven zelf juist aan dat zij zich hiernaast ook dik *voelen* en dat zij tijdens therapie vooral leren omgaan met gevoelens van dikheid, maar dat deze gevoelens desalniettemin blijven bestaan. Idealiter zouden interventies, die gericht zijn op de verstoorde beleving van lichaamsomvang bij AN, ervoor moeten zorgen dat patiënten niet langer de ervaring hebben dikker te zijn dan ze werkelijk zijn. Om dergelijke interventies te kunnen ontwikkelen is het cruciaal om inzicht te krijgen in alle aspecten van de verstoorde beleving van lichaamsomvang bij AN.

Eerder onderzoek richtte zich, net als behandeling, voornamelijk op gedachten en emoties over het lichaam en hoe hoe patiënten hun lichaam zien. Dit proefschrift gaat een stap verder, door ook te kijken naar aspecten van lichaamsbeleving op andere domeinen dan cognitie en visuele waarneming. Bijvoorbeeld, zou het zo kunnen zijn dat patiënten zich letterlijk dikker voelen dan gezonde vrouwen? En kan de verstoorde lichaamsbeleving succesvol gecorrigeerd worden? Het beantwoorden van deze vragen zal leiden tot een beter begrip van “jezelf dik voelen” bij AN.

In deze samenvatting zal ik eerst ingaan op de achtergrond van dit proefschrift: Wat is er in het verleden al gedaan op het gebied van onderzoek naar lichaamsbeleving bij AN en hoe gaan we verder? Daarna zal ik ingaan op verschillende aspecten van lichaamsbeleving bij AN die onderzocht zijn in dit proefschrift. Allereerst de waarneming van het lichaam, oftewel het *lichaamsbeeld*, daarna het lichaam tijdens beweging, oftewel het *lichaamsschema* en vervolgens het veranderen van de beleving van lichaamsomvang bij AN, oftwel *plasticiteit van* *lichaamsrepresentatie*. Tot slot komen de klinische implicaties aan bod: Wat kunnen we met de opgedane kennis in de praktijk?

1.2. Eerder onderzoek en een nieuwe kijk op de verstoorde beleving van lichaamsomvang bij AN

De verstoorde beleving van lichaamsomvang bij AN heeft veel onderzoekers de afgelopen jaren gefascineerd en geïnspireerd. Dit heeft geleid tot een groot aantal studies waarin dit onderwerp centraal stond. Eerder onderzoek naar lichaamsbeleving bij AN is voornamelijk uitgevoerd door klinisch psychologen en psychiaters. De overkoepelende conclusie op basis van deze onderzoeken is dat er bij AN patiënten een discrepantie bestaat tussen de werkelijke afmetingen van het lichaam en het interne model van het lichaam dat ligt opgeslagen in het brein, oftewel de *lichaamsrepresentatie*. Specifiek heeft eerder onderzoek aangetoond dat AN patiënten denken dat ze dikker zijn dan ze daadwerkelijk zijn en dat ze erg ontevreden zijn over hun eigen lichaam. Daarnaast heeft onderzoek vaak laten zien dat patiënten de afmetingen van hun eigen lichaam overschatten in visuele taken. Bijvoorbeeld wanneer ze een gephotoshopte foto van zichzelf (dikker of dunner gemaakt) terug moesten zetten naar de werkelijke afmetingen van hun lichaam. Er zijn echter twee factoren die de interpretatie van de resultaten van deze eerdere studies bemoeilijken.

Ten eerste, de methodologie die doorgaans gebruikt werd vindt zijn oorsprong in de perceptuele psychologie en psychofysica. Dit droeg ertoe bij dat lichamen werden gezien als gelijk aan neutrale objecten en dat er vanuit werd gegaan dat lichamen en objecten op dezelfde manier waargenomen en verwerkt zouden worden in het brein. Echter, in tegenstelling tot objecten, zijn lichamen geen neutrale statische entiteiten, maar zijn ze in principe onlosmakelijk verbonden aan emoties en attitudes. Bijvoorbeeld, wanneer een individu zijn of haar eigen lichaam waarneemt, staat deze waarneming niet los van de emotionele toestand waarin het lichaam zich bevindt, omdat het individu automatisch toegang heeft tot zowel objectieve informatie (bijvoorbeeld hoe het lichaam eruit ziet) als affectieve informatie (bijvoorbeeld hoe ik mij voel). Dit laatste type informatie is niet beschikbaar wanneer een individu een object, zoals een auto, waarneemt. Dus de waarneming en *representaties* (interne modellen in het brein) van het lichaam zijn per definitie anders dan de waarneming en representaties van (neutrale) objecten.

Een tweede complicerende factor is dat eerder onderzoek zich voornamelijk richtte op visuele perceptie, dus het letterlijk zien van het lichaam en de lichaamsomvang, waardoor er geen ruimte was voor invloeden vanuit andere zintuigen, zoals het waarnemen van aanraking (*tactiele waarneming*). Om terug te komen op het voorbeeld over het waarnemen van het eigen lichaam en een auto, wanneer het eigen lichaam wordt waargenomen heeft een individu automatisch toegang tot informatie uit verschillende zintuigen (zicht, aanraking, etc). Bij het waarnemen van de auto geldt dit niet. Een individu kan bijvoorbeeld niet voelen wat de auto zou voelen als deze aangeraakt zou worden. Dit maakt dat representaties van (de grootte van) objecten veelal gebaseerd worden op visuele informatie (wat een individu ziet), maar dat representaties van het lichaam gevormd kunnen worden op basis van meer veelzijdige (*multimodale*) sensorische informatie.

Er zou gesteld kunnen worden dat de hierboven beschreven factoren een remmende werking hebben gehad op de ontwikkeling van nieuw onderzoek naar de verstoorde beleving van lichaamsomvang bij AN. Daarnaast hebben de resultaten uit eerder onderzoek slechts beperkt geleid tot het ontwikkelen van behandelmethodes gericht op het corrigeren van lichaamsbeleving bij AN. In dit proefschrift is daarom gekozen voor een theoretisch en methodologisch nieuwe benadering van lichaamsbeleving bij AN. Hierdoor was het mogelijk nieuwe hypotheses te toetsen met behulp van innovatieve onderzoeksmethoden. Deze nieuwe benadering is gerelateerd aan neuropsychologie in de breedste zin van het woord en houdt er rekening mee dat 1) interne modellen van het lichaam (lichaamsrepresentaties) speciaal en fundamenteel anders zijn dan interne modellen van (neutrale) objecten (objectrepresentaties); en dat 2) waarneming en ervaring van het lichaam plaatsvinden in een multisensorische context (individu heeft toegang tot informatie uit verschillende zintuigen). Zodoende ondervangt de neuropsychologische benadering de eerder genoemde complicerende factoren in onderzoek naar de verstoorde lichaamsbeleving bij AN.

Vanuit een neuropsychologische benadering worden interne modellen van het lichaam gedefinieerd als abstracte, multimodale representaties van het lichaam die liggen opgeslagen in een netwerk van pariëtale, frontale en insulaire hersengebieden. Deze interne modellen van het lichaam bevatten een grote hoeveelheid aan lichaamsgerelateerde informatie. Onder andere de afmetingen van het lichaam, de locatie van het lichaam, hoe het lichaam eruit ziet en de benamingen van verschillende lichaamsdelen.

Er kan op meerdere manieren onderscheid gemaakt worden tussen verschillende interne modellen van het lichaam. Een veel gebruikt onderscheid is die tussen *lichaamsbeeld* en *lichaamsschema* (zie Figuur 1). Zowel het lichaamsbeeld als lichaamsschema is cruciaal voor ons dagelijks functioneren.

Lichaamsrepresentaties
(interne modellen van het lichaam in het brein)
Worden opgebouwd op basis van informatie uit verschillende zintuigen (zijn multimodaal)

Lichaamsbeeld
- Cognitie (kennis, gedachten, emoties over het lichaam)
- Waarneming (van & met het lichaam)
- Bewuste representatie
- Relatief stabiel over tijd

Lichaamsschema
- Plannen van acties (bewegingen)
- Uitvoeren van acties (bewegingen)
- Onbewuste representatie
- Dynamisch & constant geupdate

Figuur 1. Neuropsychologische kijk op het interne model van het lichaam in het brein.

Het lichaamsbeeld is voornamelijk van belang bij lichaamsgerelateerde cognitie en waarneming. Hierdoor kunnen we onder andere nadenken over ons lichaam en het evalueren (bijvoorbeeld door het eigen lichaam te vergelijken met dat van een ander) en weten we ook hoe ons lichaam is opgebouwd (bijvoorbeeld dat je hand vijf vingers heeft en vast zit aan je pols). Ook stelt het lichaamsbeeld ons in staat om ons lichaam waar te nemen (bijvoorbeeld in de spiegel) en mét het lichaam waar te nemen (bijvoorbeeld aanrakingen lokaliseren “iemand gaf me een tikje op mijn linkerschouder” of “er kruipt een vlieg op mijn rechterarm”). In tegenstelling tot het lichaamsbeeld is het lichaamsschema een meer onbewust intern model van het lichaam, dat voornamelijk van belang is bij het plannen en uitvoeren van acties. Het lichaamsschema bevat bijvoorbeeld informatie over de locatie van ons lichaam in de ruimte en ten opzichte van objecten of andere mensen, ook bevat het informatie over waar verschillende lichaamsdelen zich bevinden ten opzichte van elkaar en hoe ze samen een coherent geheel (één lichaam) vormen. We zijn ons doorgaans niet bewust van deze informatie, wat ervoor zorgt dat we moeiteloos bepaalde bewegingen kunnen uitvoeren, zonder hier al te veel aandacht op te richten. Bijvoorbeeld, wanneer iemand je op je linkerschouder tikt draai je meestal je hoofd automatisch naar links, of wanneer er een vlieg over je rechterarm kruipt, dan sla je automatisch de vlieg weg. Om deze bewegingen uit te voeren is het wel van belang dat je onbewust op de hoogte bent van de huidige locatie van bijvoorbeeld je linkerarm ten opzichte van je rechterarm, zodat je je linkerarm kunt bewegen richting de rechterarm, om de vlieg weg te slaan. Informatie die daarbij ook van belang is, is de snelheid en kracht waarmee je je arm beweegt; een vlieg wegslaan vergt een andere snelheid en kracht dan bijvoorbeeld met een hamer een spijker in een plank slaan.

In zowel het lichaamsbeeld als het lichaamsschema ligt ook *metrische* informatie opgeslagen over de afmetingen en vorm van het lichaam. Eerder onderzoek heeft zich tot nu toe nog niet gericht op de vraag of (multimodale) metrische aspecten van het interne model van het lichaam verstoord zouden kunnen zijn bij AN. Dit is opvallend, aangezien de metrische aspecten juist het meest relevant zijn voor AN. Patiënten voelen zich te dik, dus *groter* dan ze daadwerkelijk zijn. Het is dus belangrijk om specifiek te onderzoeken of de informatie gerelateerd aan de *afmetingen* van het lichaam, die ligt opgeslagen in het lichaamsbeeld en lichaamsschema, verstoord is bij AN. Dit zal inzicht geven in de onrealistische (te dikke) ervaring van lichaamsafmetingen bij AN.

Het doel van dit proefschrift was daarom het begrip van de verstoorde beleving van lichaamsomvang bij AN vergroten door specifiek te kijken naar metrische aspecten van het interne model van het lichaam in deze groep. Dit is onderzocht op het niveau van lichaamsbeeld, oftewel waarneming van het eigen lichaam (in Sectie 1) en lichaamsschema, oftewel uitvoeren van bewegingen met het eigen lichaam (in Sectie 2). Ook is gekeken in hoeverre de verstoorde ervaring van de afmetingen van het lichaam plastisch (veranderbaar) is en gecorrigeerd zou kunnen worden (in Sectie 3). Tezamen leveren deze onderzoeken nieuwe theoretische inzichten op die ook vertaald kunnen worden naar de therapeutische praktijk en zo de behandeling van verstoorde lichaamsbeleving bij AN kunnen verbeteren.

1.3. Sectie 1 – lichaamsbeeld stoornissen bij AN

Sectie 1 bestaat uit drie studies waarin metrische aspecten van het lichaamsbeeld onderzocht zijn. In eerder onderzoek is weinig aandacht besteed aan hoe AN patiënten aanrakingen op hun lichaam waarnemen. Wanneer we uitgaan van een meer neuropsychologische benadering van het interne model van het lichaam, dan omvat het lichaamsbeeld meer dan het letterlijke *beeld* dat we van ons lichaam hebben en hoe we over onszelf denken. Het brein ontvangt namelijk ook lichaamsgerelateerde informatie uit andere zintuigen, zoals informatie over aanraking. Deze informatie is ook van belang bij het vormen van een intern model van de afmetingen van het lichaam. Het was tot nu toe echter nog onbekend of AN patiënten aanrakingen op hun huid anders waarnemen dan gezonde vrouwen en of dit een rol zou kunnen spelen bij de verstoorde waarneming van lichaamsomvang (of ze letterlijk dikker *voelen* met hun lichaam). Daarom hebben wij een methode ontwikkeld waarmee onderzocht kan worden of AN patiënten zich dikker voelen dan ze echt zijn, iets wat ook zou aansluiten bij klinische observaties van patiënten. Voordat deze nieuwe methode om het *tactiele lichaamsbeeld* te meten gebruikt is in onderzoek met AN patiënten, is hij eerst succesvol gevalideerd in een groep gezonde participanten (zie **Hoofdstuk 2**).

In **Hoofdstuk 3** is vervolgens gekeken naar zowel visuele als tactiele verstoringen in het lichaamsbeeld bij AN patiënten. In veel eerdere studies is het visuele lichaamsbeeld voornamelijk onderzocht met behulp van taken waarbij de stimuli bestonden uit visuele informatie met betrekking tot lichaamsomvang (bijvoorbeeld een (gemanipuleerde) foto van het eigen lichaam). Vooral bij AN patiënten kan zulke a priori visuele informatie zorgen voor een bias in taakrespons, waardoor niet zozeer het visueel mentale beeld van het lichaam gemeten wordt, maar vooral lichaamsgerelateerde attitudes en emoties. Bijvoorbeeld, wanneer een patiënt een gemanipuleerde foto van haar eigen lichaam terug moet zetten naar de werkelijke omvang, dan zou ze dit kunnen doen op basis van wat ze dénkt over de foto, "ik vind mijzelf dik, dus de foto klopt met de realiteit als er een dik persoon opstaat". Wanneer dat gebeurt wordt niet het beeld dat een patiënt in haar hoofd heeft gevormd van haar lichaam gemeten, maar meer gedachtes en emoties die ze heeft over haar eigen lichaam. In het huidige onderzoek is het visuele lichaamsbeeld daarom gemeten met een methode die gebruik maakt van lichaamsgerelateerde *woorden* in plaats van afbeeldingen. Dit heeft ervoor gezorgd dat de responsen van participanten niet a priori beïnvloed konden worden door visuele informatie, maar dat participanten in hun hoofd een beeld van hun eigen lichaam creëerden. De resultaten lieten zien dat AN patiënten meer fouten maakten op deze taak, waarbij ze op basis van woorden de breedte van hun lichaam moesten beoordelen (bijvoorbeeld door zo snel mogelijk aan te geven of de afstand tussen hun heupen breder of smaller was dan de afstand tussen hun schouders). Dit impliceert dat hun spontaan gecreëerde visuele beeld van hun lichaam onrealistischer is dan dat van gezonde vrouwen.

Ten tweede zijn verstoringen in het tactiele lichaamsbeeld onderzocht. Participanten werden geblinddoekt en kregen op hun onderarm en buik tactiele stimuli (twee prikjes) aangeboden. De afstand tussen de twee prikjes moesten ze tussen duim en wijsvinger inschatten. Uit de resultaten kwam naar voren dat AN patiënten tactiele afstanden op zowel hun onderarm als buik overschatten ten opzichte van gezonde vrouwen en ten opzichte van de daadwerkelijk aangeboden afstand. Overschatting van tactiele afstanden in de AN groep geeft aan dat AN patiënten *spatiële* aspecten van aanraking anders verwerken dan gezonde vrouwen. Ze interpreteren een tactiele afstand als groter dan hij daadwerkelijk is, dus alsof een grotere oppervlakte van hun huid wordt aangeraakt. Dit zou gerelateerd kunnen zijn aan ervaren van het eigen lichaam als groter dan het in werkelijkheid is (bijvoorbeeld alsof de huid uitgerekt of opgeblazen is). De belangrijkste conclusie die getrokken kan worden op basis van de gevonden resultaten is dat er inderdaad sprake is van een stoornis in het tactiele lichaamsbeeld bij AN, wat impliceert dat niet alleen de visuele en cognitieve modaliteit aangedaan zijn.

In **Hoofdstuk 4** is het onderliggende mechanisme van de tactiele lichaamsbeeld stoornis bij AN verder onderzocht. Zou de overschatting van tactiele afstanden in de AN groep het resultaat zijn van hogere orde afwijkingen (gerelateerd aan gedachten over het lichaam), of juist gerelateerd zijn aan lagere orde afwijkingen in somatosensorische verwerking (bijvoorbeeld verwerking van aanrakingen op receptor niveau)? In overeenstemming met Hoofdstuk 3 lieten de resultaten zien dat AN patiënten en gezonde vrouwen verschillen in hoe zij tactiele afstanden schatten. Het verschil tussen de patiënten en de gezonde vrouwen was het grootst wanneer tactiele stimuli (twee prikjes) werden aangeboden op de buik, ten opzichte van de onderarm. Met andere woorden, het lijkt erop dat het interne model van lichaamsomvang in de AN groep het meest verstoord is wanneer het een lichaamsdeel betreft waarover patiënten zich ernstig zorgen maken wat betreft dikheid (de buik ten opzichte van de onderarm). Naast de tactiele schattingstaak zijn ook twee taken afgenomen die lagere orde verwerking van tactiele informatie (aanraking) meten. In de literatuur wordt verondersteld dat er geen informatie uit het lichaamsbeeld nodig is voor deze taken, maar dat de taakrespons gebaseerd is op de informatie die receptoren in de huid doorgeven aan het brein. Het interne model van het lichaam, of een verstoring hierin, is dus niet van belang voor hoe iemand presteert op deze taken. Toch lieten de resultaten zien dat er ook op deze taken verschillen waren tussen AN patiënten en gezonde vrouwen. AN patiënten waren onder andere gevoeliger voor aanrakingen op de buik (zij voelden zachte prikjes die gezonde vrouwen niet konden voelen), maar niet op de onderarm. Deze resultaten laten zien dat AN patiënten aanrakingen niet alleen als groter waarnemen, maar dat zelfs hele basale informatie over aanraking het brein al op een verstoorde manier bereikt. Verdere (regressie) analyses lieten zien dat het verstoorde lichaamsbeeld, dat kenmerkend is voor AN, hoogstwaarschijnlijk het gevolg is van een *combinatie* van hogere orde factoren die gerelateerd zijn aan AN pathologie (bijvoorbeeld negatief denken over het eigen lichaam) en lagere orde stoornissen in somatosensorische verwerking (bijvoorbeeld hoe informatie vanuit receptoren in de huid het brein binnenkomt).

Op basis van de bevindingen uit Sectie 1 kan geconcludeerd worden dat lichaamsbeeld stoornissen bij AN zich niet beperken tot verstoringen in visuele informatieverwerking, maar ook tot uiting komen in hoe aanrakingen verwerkt en waargenomen worden in deze groep. AN patiënten voelen dus als het ware dikker met hun lichaam. De exacte oorzaak hiervan is complex en lijkt gerelateerd te zijn aan zowel hogere orde als basale verwerking van lichaamsgerelateerde informatie.

1.4. Sectie 2 – lichaamsschema stoornissen bij AN

Sectie 1 richtte zich op lichaamsbeeld stoornissen in AN. Sectie 2 bevat twee hoofdstukken die gaan over het lichaamsschema, dus over hoe acties en bewegingen gepland en uitgevoerd worden.

Voorheen was de heersende opinie dat AN patiënten geen stoornissen in het lichaamsschema zouden hebben, omdat men er vanuit ging dat de kern van het probleem (het dikker ervaren van het eigen lichaam) lag in hoe patiënten over zichzelf dachten en hoe ze zichzelf (visueel) waarnamen. Echter, uit sectie 1 is al naar voren gekomen dat het verstoord beleven van het eigen lichaam dieper zit dan dat, patiënten voelen ook dikker met hun lichaam. Daarbij, uitgaande van meer neuropsychologische literatuur kan gesteld worden dat het lichaamsbeeld en lichaamsschema in bepaalde situaties met elkaar samenwerken en lichaamsgerelateerde informatie met elkaar delen. Wanneer we er vanuit gaan dat bij AN patiënten informatie, gerelateerd aan de omvang van het lichaam, verstoord wordt verwerkt of verstoord wordt opgeslagen in het brein, zou dit dus ook impact kunnen hebben op het lichaamsschema. Patiënten geven zelf vaak aan dat zij het gevoel hebben teveel ruimte in te nemen en/of te groot te zijn. Zou dit invloed kunnen hebben op, of het resultaat kunnen zijn van, hoe patiënten zich onbewust in de ruimte bewegen? Om deze vraag te kunnen beantwoorden hebben wij een nieuwe methode ontwikkeld om mogelijke lichaamsschema stoornissen bij AN patiënten te onderzoeken. Deze nieuwe methode is eerst succesvol gevalideerd in een groep gezonde participanten (zie **Hoofdstuk 5**).

In **Hoofdstuk 6** is de nieuwe methode gebruikt om lichaamsschema stoornissen bij AN patiënten te meten. In het onderzoek liepen participanten door poortjes van verschillende breedtes. Infrarood camera's registreerden al hun bewegingen. Het doel van het onderzoek was nagaan of AN patiënten en gezonde vrouwen verschilden in de breedte van het poortje waarvoor ze hun schouders begonnen te draaien. Het lopen door een (smal) poortje doet een beroep op het lichaamsschema, omdat informatie over afmetingen van het lichaam cruciaal is. Op basis van die informatie wordt beslist of een poortje breed genoeg is om rechtuit doorheen te lopen, of dat het noodzakelijk is je schouders te draaien om een botsing te voorkomen. In alledaagse situaties worden dit soort bewegingen vrij onbewust uitgevoerd. Je kunt bijvoorbeeld door een drukke straat lopen en moeiteloos andere mensen en/of objecten ontwijken zonder hier bij na te denken en ondertussen iets anders doen, zoals bellen. Om ervoor te zorgen dat participanten tijdens het onderzoek ook zonder er bij na te denken (op de automatische piloot) door de poortjes zouden lopen is hen aan het begin van het onderzoek niet verteld waar het onderzoek echt over ging. Participanten dachten dat ze deelnamen aan een onderzoek naar geheugen en voerden ook een geheugentaak uit tijdens het onderzoek. Op deze manier zijn ze succesvol afgeleid van het werkelijke doel van het onderzoek (hoe ze door de poortjes liepen).

De resultaten lieten zien dat AN patiënten en gezonde vrouwen verschillen in de breedte van het poortje waarvoor zij hun schouders beginnen te draaien zodat ze erdoorheen passen. Gezonde vrouwen draaiden hun schouders zodra een poortje 1,25 keer zo breed was als hun eigen schouders. Echter, AN patiënten draaiden hun schouders al voor relatief bredere poortjes, namelijk wanneer een poortje 1,40 keer zo breed was als hun eigen schouders. De gezonde vrouwen hadden dus een draai marge van 25% van hun eigen schouderbreedte, terwijl voor AN patiënten de draai marge op 40% van de eigen schouderbreedte lag. Met andere woorden, patiënten draaiden hun schouders al voor poortjes waar ze objectief gezien gemakkelijk rechtuit doorheen hadden kunnen lopen. De twee groepen verschilden niet op andere relevante variabelen, zoals wanneer de schouderdraai ingezet werd en de maximale draaiing van de schouders. Na afloop van het onderzoek werd participanten gevraagd hun lichaamsafmetingen in te schatten, waarbij AN patiënten hun eigen lichaamsbreedte overschatten. Opvallend genoeg bleek dat AN patiënten en gezonde vrouwen niet meer van elkaar verschilden in draai marge wanneer de geschatte lichaamsbreedte werd gebruikt om de draai marge te berekenen in plaats van de daadwerkelijke lichaamsafmetingen. Dit laat zien dat AN patiënten zich onbewust net zo breed bewegen als ze *denken* te zijn.

De bevindingen uit Sectie 2 tonen voor het eerst aan dat de verstoorde beleving van lichaamsomvang bij AN zich uitbreidt tot het lichaamsschema. AN patiënten bewegen zich in de ruimte alsof hun lichaam dikker is dan het in werkelijkheid is. Met andere woorden, hun acties worden, zonder dat ze zich hier geheel van bewust zijn, gebaseerd op een intern model van lichaamsomvang dat groter (dikker) is dan hun daadwerkelijke omvang.

1.5. Sectie 3 – plasticiteit van het interne model van het lichaam bij AN

Sectie 1 en 2 richtten zich op respectievelijk het lichaamsbeeld en het lichaamsschema. Uit de besproken onderzoeksresultaten bleek dat beide verstoord zijn bij AN. Een belangrijke volgende stap is nagaan of het verstoorde (te dikke) interne model van het lichaam in het brein *veranderd* kan worden. Sectie 3 gaat hierop in en bevat een hoofdstuk dat zich richt op de plasticiteit (maakbaarheid/flexibiliteit) van het interne model van het lichaam.

De Rubber Hand Illusie (RHI) is een methode die vanuit de neuropsychologie gebruikt wordt om de maakbaarheid/flexibiliteit van het interne model van het lichaam te meten. Tijdens de illusie zitten participanten aan een tafel en voor hen ligt een rubberen hand. Hun echte hand ligt hiernaast, maar bevindt zich achter een scherm, waardoor participanten hun echte hand niet kunnen zien. Vervolgens strijkt de onderzoeker met twee zachte kwastjes over de echte (niet-zichtbare) hand en de rubberen hand. In de experimentele conditie worden de echte hand en rubberen hand tegelijkertijd aangeraakt, wat ervoor zorgt dat het brein beide gebeurtenissen (het *zien* van de aanraking op de rubberen hand en tegelijkertijd een zelfde aanraking *voelen* op de eigen hand) integreert tot één enkele gebeurtenis. Hierdoor krijgt de participant het gevoel dat de rubberen hand onderdeel van het eigen lichaam is geworden. Participanten hebben het idee dat ze de aanraking op de rubberen hand kunnen voelen. In de controle conditie worden de echte hand en de rubberen hand niet tegelijkertijd aangeraakt, er vindt dan geen integratie plaats en de participant ervaart de rubberen hand niet als onderdeel van het eigen lichaam.

Deze methode is interessant om te gebruiken in een AN groep, omdat tijdens de illusie de rubberen hand wordt opgenomen in het interne model van het lichaam. Dit interne model van het lichaam is verstoord bij AN patiënten. Wat hierbij belangrijk is om op te merken is dat patiënten alleen de afmetingen van hun *eigen* lichaam overschatten, ze zijn wel goed in staat zijn de afmetingen van objecten of het lichaam van anderen in te schatten. Wij hebben daarom in **Hoofdstuk 7** de traditionele RHI methode aangepast door participanten voorafgaand aan en na afloop van de illusie ook te vragen de afmetingen van zowel de rubberen hand als hun eigen hand in te schatten. Dit kan laten zien of AN patiënten de afmetingen van een object (rubberen hand) anders inschatten zodra ze het ervaren als onderdeel van hun eigen lichaam na inductie van de illusie (dus wanneer de rubberen hand geïncludeerd is in het interne model van het lichaam).

De resultaten lieten allereerst zien dat op subjectief niveau AN patiënten in sterkere mate de rubberen hand als hun eigen hand ervaren dan gezonde vrouwen, wat een grotere maakbaarheid/flexibiliteit van het interne model van het lichaam impliceert. Opvallend is dat ook bleek dat de schattingen van de afmetingen van de *eigen* hand veranderden in de AN groep na inductie van de illusie, maar dat schattingen van de rubberen hand gelijk bleven. Na zowel de experimentele als controle conditie van de RHI schatten AN patiënten hun eigen hand meer accuraat in, ze vertoonden niet langer een overschatting van de afmetingen van hun hand. Het lijkt er dus op dat het voordeel dat patiënten hebben wanneer ze een object inschatten (goede schatting maken) overslaat naar het schatten van de eigen hand. Dit bleek echter niet gerelateerd te zijn aan het ervaren van de rubber hand als onderdeel van het eigen lichaam. Ondanks dat de exacte onderliggende mechanismen voor de verandering in schatting van lichaamsomvang (de hand in dit geval) niet duidelijk worden uit de huidige studie, laten de resultaten desalniettemin zien dat stoornissen in het interne model van het lichaam bij AN niet statisch zijn, maar gecorrigeerd kunnen worden.

1.6. Wat vertellen de bevindingen ons?

In het begin van dit hoofdstuk zijn twee problemen aangekaart die het interpreteren van eerder onderzoek naar de verstoorde beleving van lichaamsomvang bij AN bemoeilijken. Ten eerste werd er voorheen weinig onderscheid gemaakt tussen hoe de afmetingen en omvang van lichamen en (neutrale) objecten worden waargenomen en verwerkt in het brein, ondanks dat voor lichamen geldt dat zij niet neutraal zijn, maar in principe onlosmakelijk verbonden zijn aan emoties en attitudes, voorál bij AN patiënten. Voor hen is het lichaam en lichaamsgerelateerde informatie erg beladen. Ten tweede werd er in eerder onderzoek een grote nadruk gelegd op visuele waarneming van het lichaam en was er weinig ruimte voor informatieverwerking vanuit andere zintuigen, ondanks dat, wanneer het lichaamsgerelateerde waarneming en verwerking betreft, er vrijwel altijd sprake is van input uit meerdere modaliteiten. Het brein ontvangt niet alleen visuele informatie over het lichaam, maar ook informatie over bijvoorbeeld aanraking en waar het lichaam zich in de ruimte bevindt. In dit proefschrift is daarom de verstoorde beleving van lichaamsomvang bij AN onderzocht vanuit een neuropsychologische invalshoek. Dit zorgde voor een ondervanging van de hiervoor benoemde problemen. Ook zorgde dit ervoor dat nieuwe hypotheses opgesteld en getoetst konden worden met innovatieve methodes. In het kort zijn de belangrijkste conclusies van dit proefschrift als volgt:

- de verstoorde (dikkere) beleving van lichaamsomvang bij AN is ernstiger dan voorheen werd aangenomen en gaat dieper dan "slechts" denken dat je dik bent en jezelf zo zien;
- AN patiënten vormen in hun hoofd een onrealistisch visueel beeld van hun eigen lichaamsomvang (stoornis in visueel lichaamsbeeld);
- aanrakingen op de huid worden door AN patiënten anders (als groter) verwerkt en waargenomen (stoornis in tactiel lichaamsbeeld);
- AN patiënten baseren hun bewegingen op een vergroot intern model van hun eigen lichaam en bewegen zich dikker dan ze in werkelijkheid zijn (stoornis in lichaamsschema);
- de verstoorde beleving van lichaamsomvang bij AN is niet statisch, maar kan veranderen.

1.7. Wat kúnnen we met deze bevindingen?

De resultaten van de studies die zijn besproken in dit proefschrift hebben geleid tot een beter begrip van de verstoorde beleving van lichaamsomvang bij AN. Voorheen werd aangenomen dat AN patiënten "slechts" dachten dat zij een dik lichaam hadden en dat zij hun lichaam visueel als dikker waarnamen. In dit proefschrift is aangetoond dat de verstoorde beleving van lichaamsomvang bij AN verder gaat dan cognitieve en visuele verstoringen. De onderzoeksresultaten lieten *multimodale* stoornissen in lichaambeeld (dus zowel gerelateerd aan visuele waarneming als waarneming van aanraking) en lichaamsschema (dus gerelateerd aan het bewegen van het lichaam) zien. Deze nieuwe inzichten impliceren dat de verstoorde ervaring van de omvang van het lichaam bij AN ernstiger is dan voorheen werd verondersteld. Dit zijn interessante en belangrijke implicaties op theoretisch gebied, omdat het de kijk op lichaamsbeleving bij AN verandert. Wat echter ook belangrijk is, is de vraag, wat kúnnen we nu met deze nieuwe inzichten? Hoe kan deze nieuwe kennis de behandeling van de verstoorde beleving van lichaamsomvang bij AN verbeteren?

Zoals aan het begin van dit hoofdstuk al duidelijk werd is de verstoorde beleving van lichaamsomvang een belangrijk symptoom van AN, dat onder andere wordt gelinkt aan een ongunstige prognose en terugval. Daarnaast is de verstoorde beleving van het lichaam moeilijk te behandelen. Het is dus belangrijk om nieuwe therapeutische interventies te ontwikkelen die kunnen bijdragen aan een meer succesvolle behandeling. Tegenwoordig leren patiënten in therapie vooral hoe ze moeten *omgaan* met het zichzelf dik voelen. Uit klinische observaties blijkt dat deze gevoelens van te dik zijn echter wel vaak blijven bestaan. Met andere woorden, in huidige therapeutische interventies lukt het nog niet altijd om het interne model van het lichaam daadwerkelijk te corrigeren, zodat er sprake is van een meer realistische beleving van lichaamsomvang.

Op basis van de inzichten verkregen uit dit proefschrift hebben wij een nieuwe interventie opgezet. Deze nieuwe interventie richt zich voornamelijk op hoe AN patiënten hun lichaam gebruiken tijdens het uitvoeren van acties (bewegingen). Wat cruciaal lijkt te zijn in het veranderen van de hardnekkige overtuiging/ervaring van te dik zijn, is dat AN patiënten tijdens therapie onomstotelijk bewijs moeten krijgen betreffende hun daadwerkelijke lichaamsafmetingen. In Hoofdstuk 6 is aangetoond dat AN patiënten onbewust hun lichaam al draaien voor relatief brede poortjes, waar ze in werkelijkheid makkelijk rechtuit doorheen hadden kunnen lopen. Wanneer we deze bevindingen generaliseren kan gesteld worden dat AN patiënten een gebrek aan directe feedback over hun lichaamsomvang hebben. Ze bewegen zich alsof ze groter zijn dan ze daadwerkelijk zijn en hun brein ontvangt dus nooit een terugkoppelend signaal dat aangeeft dat bewegingen op een verkeerd (te groot) intern model van omvang zijn gebaseerd. Een voorbeeld dat het tegenovergestelde effect illustreert is dat zwangere vrouwen hun nieuwe (grotere) lichaamsomvang leren door ervaring, trial en error. Wanneer hun buik begint te groeien botsen ze regelmatig tegen dingen aan. Dit soort directe feedback geeft het brein een seintje dat het interne model van het lichaam niet meer klopt met de werkelijke afmetingen en dat het aangepast moet worden om in de toekomst botsingen te voorkomen. Bij AN patiënten gebeurt eigenlijk het omgekeerde. Zij botsen vrijwel nooit ergens tegenaan en krijgen dus geen directe terugkoppeling die aangeeft dat het interne model van lichaamsafmeting niet klopt.

Voor AN patiënten zou het daarom nuttig zijn om deel te nemen aan een interventie die wél zorgt voor dit soort directe feedback met betrekking lichaamsomvang. Er zijn twee redenen die een dergelijke interventie succesvol zouden kunnen maken. Ten eerste, het brein krijgt een directe terugkoppeling over de werkelijke lichaamsafmetingen en kan het opgeslagen interne model van lichaamsomvang hierop aanpassen. Ten tweede, door deze directe feedback over lichaamsafmeting zullen patiënten ook bewust ervaren wat hun echte afmetingen zijn. Bijvoorbeeld wanneer patiënten door een smalle opening blijken te passen waarvan ze in eerste instantie hadden verwacht dat ze klem zouden komen te zitten. Belangrijk hierbij is dat patiënten zélf door de smalle opening zijn gegaan. Bij andere therapeutische oefeningen, zoals het tekenen van het eigen silhouet en daarna de eigen lichaamsomvang hiermee vergelijken zien patiënten wel een verschil (ze krijgen visuele feedback), maar *ervaren* niet direct dat ze eigenlijk smaller zijn dan wat ze hebben getekend. In dat geval kan het voor patiënten relatief makkelijk zijn om het verschil weg te wuiven of toe te schrijven aan andere factoren dan inderdaad dunner zijn dan ze tekenden. Wanneer patiënten actief zelf bewegingen/acties uitvoeren die hen op het eerste oog onmogelijk leken (omdat ze verwachtten er te breed voor te zijn), dan ervaren ze daadwerkelijk het verschil tussen hun verwachte en echte lichaamsomvang.

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Publications

Scientific publications

Keizer, A., De Bruijn, S.E.M., Smeets, M.A.M., Dijkerman, H.C. & Postma, A. (2013). Do you know what you are doing during body scaled action? *Perception, 42,* 583-585.

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Abstracts & conference proceedings (selection)

Oral presentations

Keizer, A. (2013). Niet met iemand door één deur kunnen. Verstoorde beleving van lichaamsomvang in anorexia nervosa. *Najaarscongres Vereniging Gedragstherapie en Cognitieve Therapie (VGCT), Veldhoven, The Netherlands.*

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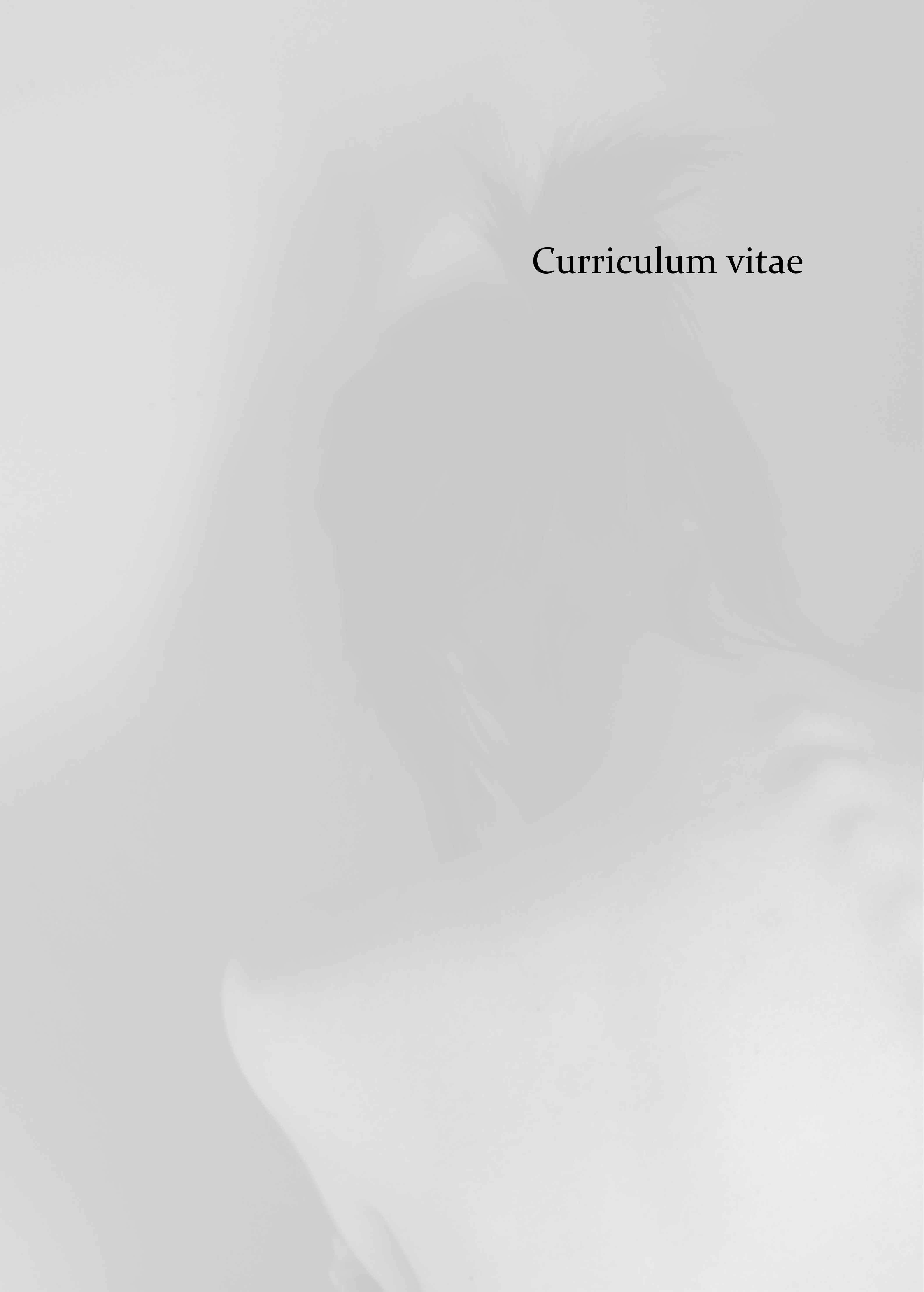
Curriculum vitae



CURRICULUM VITAE

Anouk Keizer werd geboren op 16 januari 1986 te Losser. In 2004 behaalde zij haar VWO diploma aan het St. Canisius in Almelo, waarna zij Psychologie ging studeren aan de Universiteit Utrecht. Na haar bachelor Klinische- en Gezondheidspyschologie te hebben afgerond begon zij in 2007 aan de researchmaster Psychological Health Research. Tijdens haar master thesis deed zij onderzoek naar visuele en tactiele lichaamsrepresentatie stoornissen bij anorexia nervosa patiënten. In 2009 studeerde zij cum laude af. Direct daarna kon zij haar onderzoek voortzetten en uitbereiden als promovenda op de afdeling Psychologische Functieleer van de Universiteit Utrecht. Binnen haar promotietraject heeft ze onderzoek gedaan naar zowel perceptuele als actie-gerelateerde verstoringen in de beleving van lichaamsomvang bij anorexia nervosa patiënten. Voor haar onderzoek werkte zij nauw samen met Altrecht Eetstoornissen Rintveld te Zeist. Tijdens haar promotietraject was zij ook actief als lid van de PhD Council van de Graduate School of Social and Behaviour Sciences, PhD Council van de Graduate School of Life Sciences, en chair van de PhD Council van het Helmholtz Institute. Daarnaast vertegenwoordigde zij haar collega promovendi in het Management Team van de afdeling Psychologische Functieleer. Inmiddels heeft zij een tweejarige positie als postdoctoraal onderzoeker en docent binnen de afdeling Psychologische Functieleer van de Universiteit Utrecht verworven. Hiermee zal zij vanaf april 2014 haar onderzoek naar lichaamsbeleving bij anorexia nervosa patiënten voortzetten binnen het project *"Is seeing believing? The role of multisensory input in correcting the disturbed experience of body size in anorexia nervosa"*. Dit project betreft een samenwerking tussen de afdelingen Psychologische Functieleer en Klinische & Gezondheidspsychologie van de Universiteit Utrecht en Altrecht Eetstoornissen Rintveld te Zeist.

Anouk Keizer was born on January 16th 1986 in Losser, The Netherlands. In 2004 she completed her secondary education at the St. Canisius in Almelo, after which she studied Psychology at Utrecht University. After finishing her bachelor in Clinical- and Health Psychology in 2007, she was enrolled in the research master programme Psychological Health Research. Her master thesis consisted of an experimental study focusing on visual and tactile body representation disturbances in anorexia nervosa patients. In 2009 she graduated with honors. She continued and extended this line of research as a PhD student at the department of Experimental Psychology of Utrecht University immediately after. In her PhD project she conducted multiple studies focusing on perception as well as action related disturbances in the experience of body size in anorexia nervosa patients. She performed her research in close collaboration with Altrecht Eating Disorders Rintveld in Zeist, The Netherlands. During her PhD project she was also active as a member of the PhD Council of the Graduate School of Social and Behavioural Sciences, the Graduate School of Life Sciences, and chaired the PhD Council of the Helmholtz Institute. In addition she represented her fellow PhD students in the Management Team of the department of Experimental Psychology. As of April 2014 she will be appointed as a postdoctoral researcher and teacher at the department of Experimental Psychology of Utrecht University for two years. She will continue her research on body size experience in anorexia nervosa patients on the project entitled *"Is seeing believing? The role of multisensory input in correcting the disturbed experience of body size in anorexia nervosa"*. This project is a collaboration between the department of Experimental Psychology and Clinical & Healthy Psychology of Utrecht University and Altrecht Eating Disorders Rintveld in Zeist.

Dankwoord

"The end" – The Doors

Dit is dus het begin van het einde van mijn proefschrift. En het cliché is meer dan waar, een dankwoord op papier zetten is niet gemakkelijk. Daarom doe ik het maar aan de hand van muziek.

"The four horsemen" - Metallica

Monique en Albert, jullie hebben mij onder jullie hoede genomen als master student. Wie had toen kunnen denken dat mijn afstudeeronderzoek uiteindelijk zou leiden tot een heel proefschrift.

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"Home away from here" – Touché Amoré

Naast Chris, Monique, Annemarie en Albert zijn er nog vele anderen die op hun eigen manier een steentje hebben bijgedragen aan dit proefschrift. Ik waardeer iedereens praktische en theoretische input (en gezelligheid) enorm.

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Ineke, wij spreken dezelfde taal en gelukkig kunnen onze, soms hoognodige, cola-light breaks gewoon door blijven gaan. Of het nou gaat om wetenschap of iets anders, jij hebt altijd een luisterend oor en bruikbaar advies. Helen, onze wegen hebben elkaar kort gekruist toen ik nog net niet op de afdeling werkte en jij bijna klaar was met promoveren. Ik ben blij dat je nu weer terug bent en dat de uni facebook niet blokt. Linda, een mede Zaankanter in Utrecht, dat schept toch een band, lekker samen klagen over "het dorp" en die ellendige wind op "het eiland". Bedankt ook voor alle waarschuwingen over niet-rijdende treinen. Maarten, ik heb veel van je geleerd tijdens MT, PhD coördinatie, Helmholtz, integriteits werkgroep, etc etc. En hoe kan ik Josje (team CNP!), Rick (Kakhiel), Carlijn (Billy Jeans), Franco (Lisbeth!), Jelmer (zijn het je ogen), Estrella ("ik zou een nier verkopen voor dat jasje"), Neeltje en Vivian vergeten, ook jullie bedankt voor de gezelligheid de afgelopen jaren.

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"Smoke on the water" – Deep Purple

Rook-pauzes waren de afgelopen jaren een wezenlijk onderdeel van mijn werk en soms op wetenschappelijk vlak nuttiger dan menigeen zal vermoeden. Ignace en Siarhei, ook al zijn jullie nu gestopt, bedankt voor alle keren dat we in weer en wind buiten stonden. Lieve Miranda, organiseren en structureren is een kunst, ik ben blij dat jij net zoveel van protocollen, tabbladen, weekplanners, en schrijfboeken houdt als ik (dan ik? moek toch zelf weet'n). Ik hoop dat de komende jaren net zo leuk worden (zowel tijdens als na werktijd) als de jaren hiervoor. Bedankt voor alle lieve (en rare) post-its en alle keren dat ik moest huilen van het lachen om je verhalen (tikkie theatraal, ja maarja). NB. Sorry voor Upcoming.nl. Ivo, ik moet altijd zo om je lachen (vooral om je booty-shakes). Bedankt voor alle keren dat je me ongeduldig kwam ophalen om te roken. Dat was de perfecte manier om lol te hebben, te klagen over reviewers (plus al het andere wat klaag-waardig is) en belangrijke levensvragen te bespreken (moest je roze koeken nou eten vóór of ná sneeuwwitjes?). Enne, waar blijft dat blikje cola? Sascha, menig sigaret hebben we samen gerookt, op en buiten de uni. Wat hadden we het leuk, bier in Bochum, pizza scheuren in Rome, oververhitting op Lowlands, samen eten, en avondjes naar het concertgebouw.

"The Scientist" - Coldplay

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And you're my obsession, I love you to the bones / "Ana's song" - Silverchair

Zonder alle meiden van Rintveld die hebben meegedaan aan mijn onderzoeken was dit proefschrift er nooit geweest. Een aantal van jullie hebben niet aan één maar zelfs meerdere onderzoeken meegedaan. Ik heb sommigen van jullie zien opbloeien, en anderen zien terugvallen. Hoe dan ook was elke ontmoeting en weerzien voor mij een motivatie om hard te blijven werken. Deelname aan onderzoek was voor jullie niet altijd even leuk, maar toch deden jullie het, grote dank hiervoor.

"Never gonna give you up" – Rick Astley

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"Zonder vrienden kan ik niet" – Boudewijn de Groot

Naast hard werken is het ook belangrijk om op z'n tijd te ontspannen en even niet met wetenschap bezig te zijn. En hoe dat beter te doen dan met vrienden. Zaanse vriendinnetjes en vrienden, onze groep wordt steeds groter. Rocco & Sandrien, Cyndia & Michiel, Bart & Evaline, Janneke & Filipe, Borrie & Sjaq, Kil & Suuz, Peter & Aimee, Emmy & Giel, Hildr (en alle anderen), met jullie is het leven een stuk minder saai. In de kroeg, op verjaardagen, bij optredens van de Mieters, tijdens bbq's, het is altijd gezellig. Zelfs als om twee uur het bier al op is kan het feest gewoon tot vijf uur doorgaan. Sandrien, één blik en een half woord is voor ons genoeg. Ik hoef jou niet uit te leggen waarom ik dingen doe zoals ik ze doe, want je snapt het toch wel. Het is fijn om nu in Zaandam iemand te hebben met wie ik een Twentse geschiedenis (en genen) deel. Tony en Laurens, we zijn al heel wat concerten en festivals afgegaan, wat had ik het nodig soms. We hebben zoveel leuke mensen ontmoet om mee te slammen, te grinden en te beuken, laten we daar vooral mee doorgaan \m/. Net als met après ski barren bezoeken, gin tonics drinken en Steen luisteren. En iets met blond of dreads.

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“Come as you are” - Nirvana

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“All in the family” - Korn

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"Het Dorp" – Wim Sonneveld

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"Bliss" - Muse

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“Don’t stop me now” – Queen

Anouk