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Aberrant somatosensory perception in Anorexia Nervosa

Anouk Keizer[a,*], Monique Aldegonda Maria Smeets[b], Hendrik Christiaan Dijkerman[a], Annemarie van Elburg[c], Albert Postma[a,d]

[a] *Utrecht University, Faculty of Social and Behavioural Sciences, Experimental Psychology, Helmholtz Institute, Utrecht, The Netherlands*
[b] *Utrecht University, Faculty of Social and Behavioural Sciences, Department of Clinical and Health Psychology, Utrecht, The Netherlands*
[c] *Altrecht Eatind Disorders Rintveld, Zeist, The Netherlands*
[d] *Department of Neurology, University Medical Centre Utrecht, Utrecht, The Netherlands*

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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. Tactile size perception was measured with the Tactile Estimation Task (TET) (see Keizer et al., 2011). Elementary somatosensory perception was assessed with a pressure detection task and two point discrimination (TPD). 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 TPD on both the arm and abdomen. Regression results implied that group membership predicted tactile size estimation on the arm. Both group membership and TPD 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 could 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 (American Psychiatric Association, 2002). 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 and 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 made (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 behaviors, 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., 2011). 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

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[*] Corresponding author. Tel.: +31 0302531897; fax: +31 0302534511.
E-mail address: A.Keizer@uu.nl (A. Keizer).

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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.; Smeets, 1997; Skrzypek et al., 2001). 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 et al., 2005; 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 et al., 2005; 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., 2005; 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 second 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 the higher order somatosensory task, activation in these areas was stronger than for the 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; Papežová et al., 2005). Elevated pain thresholds have been found in AN patients as well (Papežová 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. Method

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

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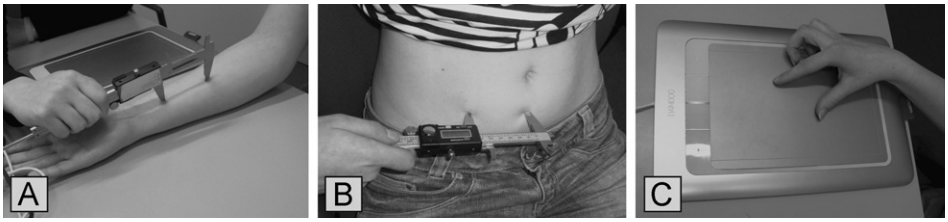

Fig. 1. Example trials of the Tactile Estimation Task (TET): (A) Stimuli presentation on the right forearm; (B) stimuli presentation on the right side of the abdomen; and (C) size estimation of the tactile stimuli on a touchpad.

Specified (EDNOS) patients), the healthy control group consisted of 28 undergraduate students. Participants received a monetary reward for a 60 min 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 (American Psychiatric Association, 2002). 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 (± 4.24) for the patient group and 22.54 (± 2.52) for the control group, $t(51)=1.72$, $P=0.092$. 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, $t(51)=-5.01$, $P<0.001$, with a mean of 18.96 (± 2.18) for the patient group and 21.30 (± 1.76) for the control group. Patients had a mean disease duration of 7.96 (± 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, $t_{patients}(24)=-8.22$, $P<0.001$ ($\text{mean}_{arm}=0.92$, ± 1.29; $\text{mean}_{abdomen}=3.16, \pm 1.21$); $t_{controls}(27)=-2.92$, $P=0.007$ ($\text{mean}_{arm}=0.07$, ± 0.26; $mean_{abdomen}=0.68$, ± 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, $t_{arm}(25.78)=3.23$, $P=0.003$; $t_{abdomen}(51)=7.96$, $P<0.001$, 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 4 weeks. Cooper et al. (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 TET (adapted version based on Anema et al., 2008; De Vignemont et al., 2005; Taylor-Clarke et al., 2004, see also Keizer et al., 2011) 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 Fig. 1A) or right side of their abdomen (see Fig. 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 Fig. 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®, 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.

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^{TM} 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, Wetherhill 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 TPD task (see e.g., Lundborg and Rosén, 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, Wetherhill and Levitt, 1965). The TPD 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, $F(2,102)=0.56$, $P=0.571$. BMI was not included as a covariate as it did not correlate with TET scores, $r_{AN}=-0.38$, $P=0.061$; $r_{controls}=-0.07$, $P=0.720$. The mean distance estimation in the TET was 69.82 (± 12.29) for the patient group ($\text{mean}_{arm}=70.87$, $\pm_{arm}12.59$; $\text{mean}_{abdomen}=68.77$, $\pm_{abdomen}14.94$), and 50.56 (± 11.36) for the control group ($\text{mean}_{arm}=55.78$, $\pm_{arm}13.99$; $\text{mean}_{abdomen}=45.34$, $\pm_{abdomen}13.53$) (see also Table 1).

A mixed repeated measures ANOVA showed a main effect for group, $F(1,51)=35.16$, $P<0.001$, $d=1.65$ and body part, $F(1,51)=1.20$, $P=0.002$, $d=0.36$. More importantly, an interaction between

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[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 and Fidell (2007).

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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			Healthy controls		Repeated measures ANOVA			
Task	*M*	S.D.	*M*	S.D.	Task	Effect	*F*	*P*
TET (size estimation)	69.82	12.29	50.56	11.36	TET (size estimation)	Main effect Group	35.16	< 0.001
TET arm	70.87	12.59	55.78	13.99		Main effect Body part	1.20	0.002
TET abdomen	68.77	14.94	45.34	13.53		Group*Body part	4.53	0.039
VF (detection)	0.23	0.07	0.27	0.11	VF (detection)	Main effect Group	2.01	0.163
VF arm	0.28	0.12	0.22	0.11		Main effect Body part	0.11	0.743
VF abdomen	0.19	0.10	0.32	0.14		Group* Body part	21.27	< 0.001
TPD (discrimination)	35.79	5.01	32.62	5.15	TPD (discrimination)	Main effect Group	4.78	0.034
TPD arm	36.52	5.15	34.10	6.73		Main effect Body part	3.21	0.080
TPD abdomen	35.06	8.21	31.14	6.20		Group*Body part	0.37	0.546

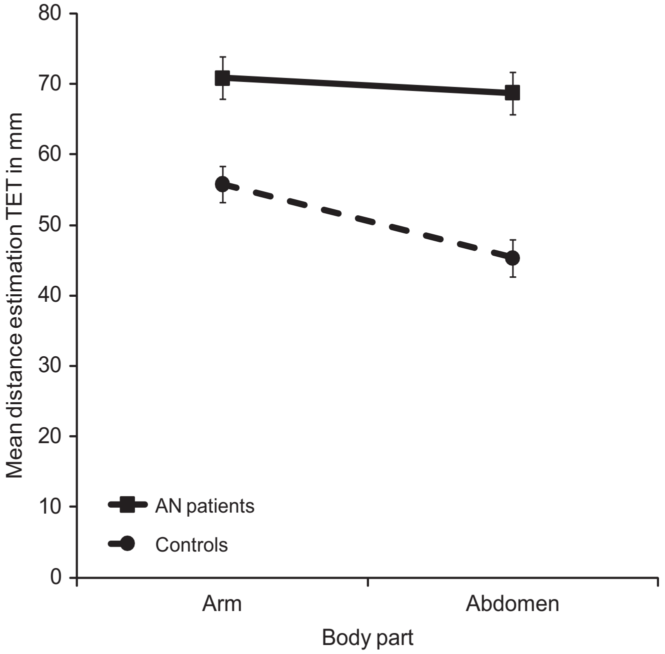

Fig. 2. Mean distance estimations in the Tactile Estimation Task (TET) in mm by participant group and body part. Anorexia Nervosa (AN) patients estimate tactile distances on both the arm and abdomen as larger than controls do. This effect is largest for stimuli presented to the abdomen. Error bars depict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

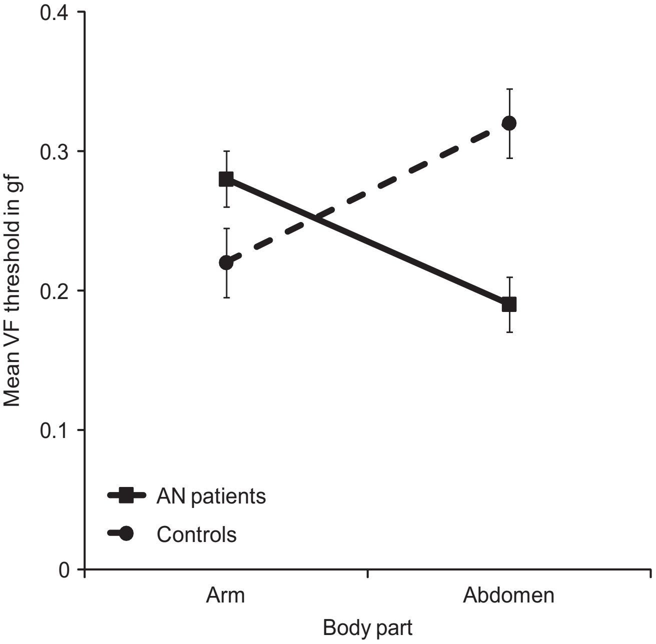

Fig. 3. Mean Von Frey (VF) pressure detection thresholds in gf by participant group and body part. Anorexia Nervosa (AN) patients and controls perform equally well in detecting pressure on the arm. AN patients have a lower threshold than controls for detecting pressure on the abdomen. Error bars depict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

body part and group was found, $F(1,51)=4.53$, $P=0.039$, $\eta^2=0.07$ (see Table 1 and Fig. 2). *Post hoc* Bonferroni corrected independent samples *t*-tests indicated that on both the arm $t(51)=4.11$, $P<0.001$, $d=0.20$, and abdomen $t(51)=5.99$, $P<0.001$, $d=1.70$, 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, $t(27)=3.55$, $P=0.001$, $d=0.77$, but not for the patient group, $t(24)=0.83$, $P=0.415$, $d=0.15$.

Taken together, patients made larger distance estimations in the TET than controls on both the arm and the abdomen. Further, the difference in distance estimation between the groups was largest on the abdomen, thus the body part that participants were most concerned about in terms of fatness.

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, $r_{AN}=-0.42$, $P=0.054$; $r_{controls}=0.18$, $P=0.384$. The mean pressure detection threshold in gf was 0.23 (± 0.07) for patients ($\text{mean}_{arm}=0.28$, $\pm_{arm}0.12$; $\text{mean}_{abdomen}=0.19$, $\pm_{abdomen}0.10$), and 0.27 (± 0.11) for controls ($\text{mean}_{arm}=0.22$, $\pm_{arm}0.11$; $\text{mean}_{abdomen}0.32$, $\pm_{abdomen}=0.14$) (see also Table 1).

A mixed repeated measures ANOVA showed no main effect for group, $F(1,46)=2.01$, $P=0.163$, $\eta^2=0.04$, or body part, $F(1,46)=0.11$, $P=0.743$, $\eta^2=0.00$. However, an interaction between body part and group was found, $F(1,46)=21.27$, $P<0.001$, $\eta^2=0.32$ (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 $t(46)=-3.78$, $P<0.001$, but not for the arm $t(46)=1.64$, $P=0.107$ (see Fig. 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, $t(21)=2.46$, $P=0.023$, and control group, $t(25)=-4.49$, $P<0.001$.

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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. TPD 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 TPD threshold, $r_{AN}=0.24$, $P=0.263$; $r_{controls}=0.13$, $P=0.539$. The mean TPD threshold was 35.79 (±5.01) for patients ($mean_{arm}=36.52$, $\pm_{arm}5.15$; $mean_{abdomen}=35.06$, $\pm_{abdomen}8.21$) and 32.62 (±5.15) for controls ($mean_{arm}=34.10$, $\pm_{arm}6.73$; $mean_{abdomen}=31.14$, $\pm_{abdomen}6.20$) (see also Table 1).

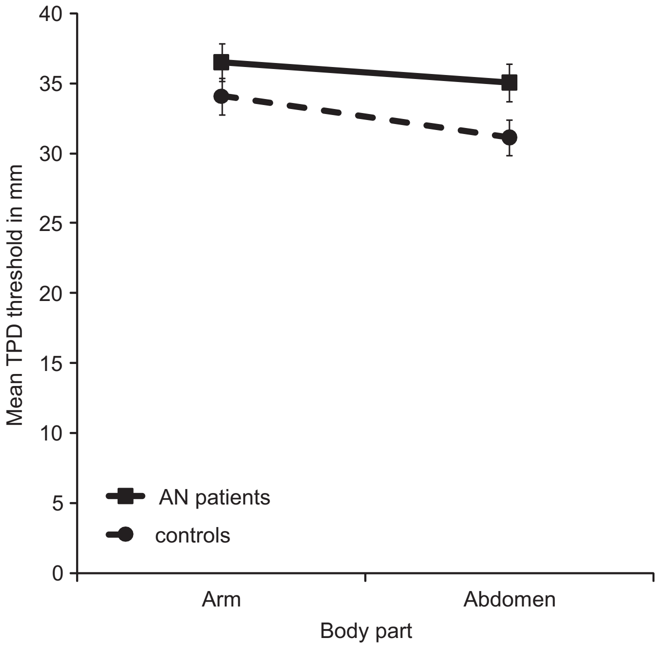

Fig. 4. Mean two point discrimination (TPD) thresholds in mm by participant group and body part. Independent of body part, Anorexia Nervosa (AN) patients have a higher two point discrimination threshold compared to controls. Error bars depict the s.e.

A mixed repeated measures ANOVA showed a main effect for group, $F(1,47)=4.78$, $P=0.034$, $d=0.60$. Neither a main effect for body part, $F(1,47)=3.21$, $P=0.080$, $d=0.31$, nor an interaction between body part and group, $F(1,47)=0.37$, $P=0.546$, $\eta^2=0.04$, 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 Fig. 4).

3.3. Relation between body dissatisfaction and tactile perception

Patients showed significantly higher levels of body dissatisfaction compared to controls, $t(31.38)=5.97$, $P<0.001$, $d=1.72$, with a mean total BSQ score of 85.72 (±41.87) for the patients and 31.96 (±17.48) for the control group. These results indicate that over the past 4 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 TPD 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 0.32, $\Delta R^2=0.11$, $P=0.011$. Including the interactions between group and body dissatisfaction, pressure detection and TPD in Model 3A (see Table 2) did not result in significant changes in explained variance, $\Delta R^2=0.03$, $P=0.667$.

Analyses for the abdomen showed that body dissatisfaction, as well as both pressure detection and TPD significantly predicted TET distance estimation on the abdomen, $R^2=0.32$ (Model 1B, Table 2). However, after group was added as a predictor in Model 2B (see Table 2), only group and TPD significantly predicted TET distance estimation on the abdomen. The explained variance significantly increased to 0.58, $\Delta R^2=0.26$, $P<0.001$. Adding the interaction between group and the remaining predictors in Model 3B (see Table 2) did not result in significant changes in explained variance, $\Delta R^2=0.04$, $P=0.324$.

Table 2
Results of the regression analyses by body part.

Dependent variable: TET (size estimation) on the arm				Dependent variable: TET (size estimation) on the abdomen			
	Predictor variable	β	P		Predictor variable	β	P
Model 1A	BSQ (dissatisfaction)	0.37	0.011	Model 1A	BSQ (dissatisfaction)	0.34	0.013
	VF arm (detection)	0.24	0.092		VF abdomen (detection)	−0.33	0.015
	TPD arm (discrimination)	0.01	0.969		TPD abdomen (discrimination)	−0.29	0.031
Model 2A	BSQ	0.07	0.672	Model 2A	BSQ	−0.11	0.435
	VF arm (detection)	0.15	0.254		VF abdomen (detection)	−0.02	0.901
	TPD arm (discrimination)	−0.04	0.743		TPD abdomen (discrimination)	−0.45	< 0.001
	Group	−0.47	0.011		Group	−0.81	< 0.001
Model 3A	BSQ (dissatisfaction)	0.04	0.852	Model 3A	BSQ (dissatisfaction)	−0.09	0.572
	VF arm (detection)	0.28	0.164		VF abdomen (detection)	0.22	0.334
	TPD arm (discrimination)	0.12	0.613		TPD abdomen (discrimination)	−0.39	0.006
	Group	0.29	0.767		Group	−0.13	0.809
	Group*BSQ	0.14	0.545		Group*BSQ	−0.15	0.422
	Group*VF arm	−0.27	0.404		Group*VF abdomen	−0.46	0.225
	Group*TPD arm	−0.64	0.442		Groep*TPD abdomen	−0.27	0.575

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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 TPD. Specifically, being diagnosed with AN and having a low TPD threshold predicted larger distances estimation on the abdomen in the TET.

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 TPD (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 TPD 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 provides 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 TPD. 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 behavior (American Psychiatric Association, 2002) 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 TPD and thus underlie, in a bottom-up fashion, the shown group differences in tactile size estimation.[2] 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 (American Psychiatric Association, 2002), 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

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[2] Note that we did not find a relation between BMI and the tactile tasks in the AN group and control group. However, the samples were relatively small. Within the AN group a trend was found, suggesting a negative relation between BMI and tactile size estimation, and a negative relation between BMI and pressure detection. It is suggested to take BMI into consideration in analyses in future studies with a larger sample size.

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and Gallace, 2007 for a review). Furthermore, 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.

Counterintuitvely, 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 behavior 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.

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