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Women with Anorexia Nervosa do not show altered tactile localization compared to healthy controls

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ABSTRACT

Body image disturbance is a key symptom of Anorexia Nervosa (AN). Previous studies found that women with AN overestimate their body size in comparison with healthy controls (HC), at least for unimodal measures involving either only visual input (e.g. distorted photographs technique) or only tactile input (e.g. tactile distance tasks). Distorted body representations are hypothesized to cause this misperception in AN. We here tested whether this overestimation remains present in a novel one-point-localization (OPL) task involving the mapping of a tactile stimulus onto a visual image. Two experiments compared the ability of 27 women with AN and 40 HC to accurately localize a tactile stimulus on a live image of their body. Women with AN and HC did not differ in their performance. Instead, participants in both groups showed systematic distortions in their localization performance. This study suggests that the mapping of a tactile stimulus does not involve a distorted body representation in women with AN compared to HC.

1. Introduction

Anorexia Nervosa (AN) is a severe mental disorder characterized by a significant low body weight, an intense fear of gaining weight and a body image disturbance (American Psychiatric Association, 2013).

Body image disturbance in AN manifests itself both at a cognitive-affective level (e.g. body dissatisfaction) as well as at a perceptual level (Bruch, 1962; Cash and Brown, 1987; Garner and Garfinkel, 1981). In the scientific literature altered body perception in women with AN is mainly discussed in the context of an overestimation of body size and shape (Gaudio et al., 2014). However, this overestimation has primarily been assessed in unimodal paradigms (Gaudio et al., 2014) using for example body size estimation (BSE) tasks (Bowden et al., 1989; Cash and Deagle, 1997; Farrell et al., 2005; Gardner and Brown, 2014; Meermann et al., 1986; Skrzypek et al., 2001) or tactile distance tasks (Engel and Keizer, 2017; Keizer et al., 2012, 2011; Spitoni et al., 2015).

One aspect of body perception, which has been largely overlooked in women with AN, is tactile localization (Gadsby, 2017). Tactile localization refers to the localization of a tactile stimulus on the skin. The facts that touch receptors are localized within the skin and that the skin is the surface covering the whole body underline the important role of the sense of touch in informing the individual of its body size (Serino and Haggard, 2010). Determining a perceived location on the skin (on an image) of the touched body part requires body representations that go beyond somatosensory cortical information. Somatosensory cortical maps only contain information about the size of body parts based on tactile sensitivity, however, this information does not convey the true size and shape of the body (Gadsby, 2017; Longo et al., 2010; Medina and Coslett, 2010; Serino and Haggard, 2010). Body representations can be defined as dynamic models of one's body (Berlucchi and Aglioti, 2010; Gadsby, 2017). Based on studies of double dissociations in neurological patients (Head and Holmes, 1912; for a review see Longo et al., 2010), a common differentiation was made between the body image and the body schema with the body image being involved in perception and thoughts/attitudes pertaining to the body and the body schema being associated with action-related guidance of the body (de Vignemont, 2010; Gallagher, 2006). According to this definition both the body image (e.g. Farrell et al., 2005; Gaudio et al., 2014; Keizer et al., 2011) and the body schema (Guardia et al., 2010; Keizer et al., 2013; Metral et al., 2014) have been shown to be distorted in women with AN. The classical dyadic differentiation of body representations might not suffice however, and extensions such as

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the tactile form, a body representation involved in tactile processing, have been proposed (Gadsby, 2017).

The aim of the present study is to investigate visuo-tactile body perception in AN by use of a one-point-localization (OPL) task. Localization tasks have long been used to study distortions in perception (Head and Holmes, 1912; Longo et al., 2015; Rapp et al., 2002; Steenbergen et al., 2014). The deviation between the actual and estimated point of touch can be quantified both by its magnitude (in the following referred to as overall deviation) and by the direction of deviation (Polo and Felicísimo, 2010). We here present a novel adaptation of the localization paradigm, which requires participants to localize a tactile stimulus applied to their skin on a screen showing a live image of the touched body part.

We argue that this kind of task has two specific benefits: First, although (primarily visual) BSE tasks have been long hailed as the most direct way to assess perceptual disturbances in AN (Farrell et al., 2005; Gardner and Brown, 2014), the concept has also been criticized (Hsu and Sobkiewicz, 1991; Mölbert et al., 2018; Smeets, 1997), in particular for its susceptibility to cognitive-affective (top-down) influences by asking explicitly for BSE. For example, viewing an image of the body is assumed to be highly stressful for women with AN, who are most often highly dissatisfied with their body. Thus, BSE tasks are suggested to be influenced by the negative thoughts about one's body (Mölbert et al., 2018). Further, it might be that women with AN more or less consciously overestimate their body size in order to justify their desire to lose weight. Interesting in this regard is that women with AN generally tend to overestimate their own body size, but do not do so for other persons or objects (Bowden et al., 1989; Guardia et al., 2012; Slade and Russell, 1973). BSE tasks therefore inquire rather directly about the subjective perception of the body. This does not allow for distinguishing between cognitive-affective influences and perceptual (bottom-up) disturbances (Mölbert et al., 2018). The OPL task is designed to minimize cognitive-affective influences by presenting an image of the body on which the body's boundaries are obscured. Thus, the task neither focuses on body outlines, nor inquires directly about body size or distances on the body, terms that are semantically strongly connected to those aspects of body image that are particularly sensitive for women with AN. Instead, the body outlines have to be estimated implicitly and the focus of the task is on stimulus localization, a neutral aspect of body perception. Second, the OPL task thus requires the subject to map tactile input onto a visual representation of the body. Cross-modal perception tasks, in which different sensory modalities have to be combined have been investigated rarely in AN (Case et al., 2012; Eshkevari et al., 2012; Keizer et al., 2014). However, multisensory information is indispensable to continuously update body representations (Kammers et al., 2010). Specifically, the appropriate combination and integration of different sensory modalities is integral in creating a unified perceptual representation of the human body in the brain (Heed, 2010; Siemann et al., 2015). Touch (Azañón et al., 2010; Longo et al., 2010; Medina and Coslett, 2010; Serino and Haggard, 2010; Spitoni et al., 2010) and vision in particular are suggested to play a major role in the formation of body representations (Press et al., 2004). Note here, that cross-modal perception in this task implies estimating (implicitly) the body silhouettes visually and then mapping the perceived tactile stimulus onto that image.

The results of two experiments are presented here. In Experiment 1 we examined OPL at the back while participants were sitting upright. In Experiment 2 we investigated OPL at the back and the abdomen, to take into account differences in emotional distress associated with emotionally sensitive body parts.

We firstly hypothesized that women with AN would show a greater overall deviation between the location of the applied tactile stimulus and the location estimated by the participant compared to healthy controls (HC; hypothesis 1). This hypothesis was examined by investigating the magnitude of deviation, i.e. the overall deviation. In light of the results of studies showing perceptual (i.e. tactile) overestimation of body width in women with AN (Keizer et al., 2016, 2012, 2011; Spitoni et al., 2015), we secondly hypothesized that women with AN would show a systematic deviation in lateral direction (hypothesis 2). The second hypothesis was examined by use of circular statistics, which investigated the direction of deviation. We furthermore hypothesized that both magnitude and the bias in lateral direction would be more pronounced for the abdomen than for the back, given that previous studies generally have found greater effects on those body parts that are especially strongly connected to concerns about body size (Keizer et al., 2014, hypothesis 3). Here, overall deviation and the direction of deviation were taken into account to clarify whether there is a difference in the two body parts tested.

2. Experiment 1

In Experiment 1 we examined OPL at the back while participants were sitting upright.

2.1. Methods

The study was conducted in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) and was approved by the local ethics committee of the Department of Sports Sciences and Psychology of the University of Münster (Wagner_03_14, HW1).

2.1.1. Participants

Prior to enrolment in the study informed written consent was obtained from the 33 female participants (17 women with AN, 16 HC). One AN patient and one HC were excluded as they did not adhere to study procedures. Data of 31 participants (16 women with AN and 15 HC) were analyzed. Results of descriptive statistics are shown in

Table 1
Descriptive statistics of participants in Experiment 1 and Experiment 2.

	Experiment 1		Experiment 2	
	AN	HC	AN	HC
Age (years)	27.44 ± 9.20	25.60 ± 2.97	29.33 ± 11.18	22.63 ± 3.61
BMI (kg/m^2)	15.70 ± 1.04	21.48 ± 2.19	18.26 ± 2.24	21.98 ± 2.36
Disease duration (years)	7.81 ± 8.67	–	6.63 ± 9.98	–
Treatment duration (weeks)	5.32 ± 4.66	–	8.47 ± 7.46	–
DKB$_{mean}$	–	–	2.6 ± 0.7	3.7 ± 0.4
Vitality	–	–	3.0 ± 1.0	4.0 ± 0.6
Self-acceptance	–	–	2.2 ± 1.0	3.7 ± 0.5
Body-contact	–	–	2.9 ± 1.2	4.0 ± 0.6
Sexual Fulfillment	–	–	2.4 ± 1.0	3.9 ± 0.7
Self-achievement	–	–	2.3 ± 1.0	3.0 ± 0.5

Values are reported as mean ± standard deviation. Vitality, Self-acceptance, Body-contact, Sexual Fulfillment and Self-achievement are the subscales of the DKB-35.

Table 1. All women with AN were hospitalized during the time of the study. Two women were diagnosed with an atypical AN (F50.1), which means that they fulfilled all diagnostic criteria for AN, except for the low BMI (>17.5). The remaining 14 women were diagnosed with AN (F50.0). In addition, 13 women were diagnosed with a co-morbid depression of medium intensity. Diagnosis of AN was defined by clinical interviews in accordance with the 5th edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-V; American Psychiatric Association, 2013) and based on the Eating Disorder Inventory (EDI; Garner et al., 1983). All women with AN received psychotherapeutic treatment based on cognitive behavioral therapy (CBT). In addition to group and individual therapy sessions, they received nutrition and movement therapy, as the treating clinics pursue a holistic, interdisciplinary approach. The control group consisted of students or employees of the participating hospitals. They had no history of neurological or psychiatric disorders, were in good health, and were not on medication. Exclusion criteria for controls included the presence of any type of AN verified with the short checklist for AN of the EDI (EDI-3SC; Garner et al., 1983).

2.1.2. Procedures

The test duration for each participant was approximately 20 min. The participants were extensively informed about the study procedures, both in a preparation talk immediately before participation and also via an information letter they had received earlier. The participants were asked to undress to the waist to avoid any kind of orientation points on the live image, such as bra straps, and to sit down on a chair (Fig. 1A). Three reference markers with a diameter of 1 cm were placed on their backs at the 7th vertebra of the cervical part of the spine (C7) and both fossae lumbales laterales (two pits in the lower part of the back; Fig. 1B). These markers allowed defining a local coordinate system during data analysis. The participants faced a laptop, which was placed on a table in front of them, while a camera (Philips SPC 900NC; 480 × 640 pixels) was positioned behind them. The investigator (JM) sat down behind the participants in such a way that the participants' entire back could be touched without obscuring the camera's view. During the experiment, the investigator touched the participants' back at random spots across the entire back using a rubber stick with a diameter of 3 mm. In each trial, the participants were instructed to click the laptop's mouse as soon as they perceived a touch on their back. With this first click, a first photograph of their back was taken. This response also served to ensure that the participants had actually felt the stimulus. Five seconds after the mouse click the monitor displayed a live image of the participants' back with the outlines obscured (Fig. 1B). The participants were then asked to place the cursor at the position of the perceived touch on the live image and confirm this position with a second mouse click. The coordinates of the estimated touch were saved and a second photograph was taken. This procedure was repeated 50 times.

2.1.3. Data analyses

All trials were visually inspected and invalid trials were excluded. Location of stimulus application and of stimulus localization were determined based on the first and second photograph, respectively, using custom-made software developed in Matlab (Mathworks Natick, USA; version R2015a, The Mathworks Inc., 2016). For each photograph a local coordinate system was constructed using the coordinates of the three reference markers on the back (Fig. 2A). The origin of this coordinate system was situated at the center point (P_0) between the two markers on the fossae (dashed line), with the cranio-caudal *y*-axis extending from P_0 to the C7-marker and being vertical to the *x*-axis. Doing so, we could reliably determine the coordinates of both the recorded (i.e. applied) and indicated (i.e. estimated) positions.

2.1.3.1. Overall deviation. Overall deviation between the coordinates of the applied A (x/y) and the estimated E (x/y) points of contact were calculated as the Euclidian distance $\mathrm{Dev}=\sqrt{\mathrm{Hor}^2+\mathrm{Ver}^2}$, with $\mathrm{Hor}=E_x-A_x$ being the horizontal deviation and $\mathrm{Ver}=E_y-A_y$ being the vertical deviation (Fig. 2B). In order to control for differences in back length, data were normalized by dividing each outcome by the individual distance between P_0 and C7 (i.e. the defined back length).

2.1.3.2. Direction of deviation. To investigate the direction of deviation circular statistics were used (Berens, 2009; all algorithms are available as part of the CircStats toolbox). For each of the 50 trials that were conducted per participant the deviation vector ($\vec{r}$) was used to deduce the angular direction (α). Hence, we could infer different directions of deviations based on angular ranges (Fig. 2B). Mean angular direction (α_{mean}) as well as the standard deviation were calculated for both each subject separately and also the two groups (AN and HC). The length of the mean resultant vector (*R*; inverse analogue of the variance of linear data) was used to indicate the distribution of the deviations. The closer *R* is to one, the more the estimated stimuli are distributed around the mean direction, indicating a systematic bias. The closer *R* is to zero, the more the estimated stimuli are distributed in all directions, indicating a uniform distribution.[1]

2.1.4. Statistics

2.1.4.1. Overall deviation. Statistical analyses were conducted using Matlab. To investigate whether participants differed with regard to the overall deviation between applied and estimated touch, a non-parametric Wilcoxon Ranksum test (alpha level 5%) was conducted, as a Kolmogorov Smirnov test showed that the data were not normally distributed. Nevertheless, since we assumed that there may be more outliers in the AN group, mean values instead of median values were used in order to include all possible outliers.

2.1.4.2. Direction of deviation. The Rayleigh test (alpha level: 5%) was used to check if the data of the participants were uniformly distributed, i.e. if the data were random (Fig. 5A) or had a preference for a specific direction (unimodal; Fig. 4C) (Berens, 2009). The Rayleigh test uses *R* to compare randomness to an undefined unimodal distribution and is thus suited for detecting a unimodal deviation from uniformity (Berens, 2009; Fisher, 1993). A unimodal distribution suggests that there is a systematic bias. By implication, a significant result would mean that the data (i.e. estimated stimuli) were non-uniformly distributed. Also, if α_{mean} lies between 0–90° or 270–360° a systematic bias in lateral direction can be inferred.[2] The Rayleigh test was applied over all trials for any individual, as a measure of the individual's systematic bias, as well as over the mean angles of all participants in a group, reflecting a systematic bias within each group as a whole. Note, that in the case that participants deviate in opposite directions, angular mean directions cancel each other out, resulting in a uniform distribution for the whole group as assessed with the Rayleigh test.

2.2. Results

2.2.1. Overall deviation

Overall deviation did not differ between both groups ($Dev_{AN}=0.12 \pm 0.05$, $Dev_{HC}=0.10 \pm 0.03$; $Z=0.73$; $p=0.465$). Note that the deviations are normalized to back length, which, given an average back length of approximately 50.0 cm translates to absolute deviations of circa 6 cm from the actually applied stimuli. (For results of horizontal and vertical deviation see supplemental material 1.)

2.2.2. Direction of deviation

Analyses of the direction of deviation showed that the responses of

[1] Note that small values of R do not necessarily indicate that the data are uniformly distributed; this can also be due to a bimodal distribution (i.e. that there are two clusters in the data).

[2] A non-significant result would imply that the data were uniformly distributed and that there was practically no relevant α_{mean} (Marques De Sá, 2007)

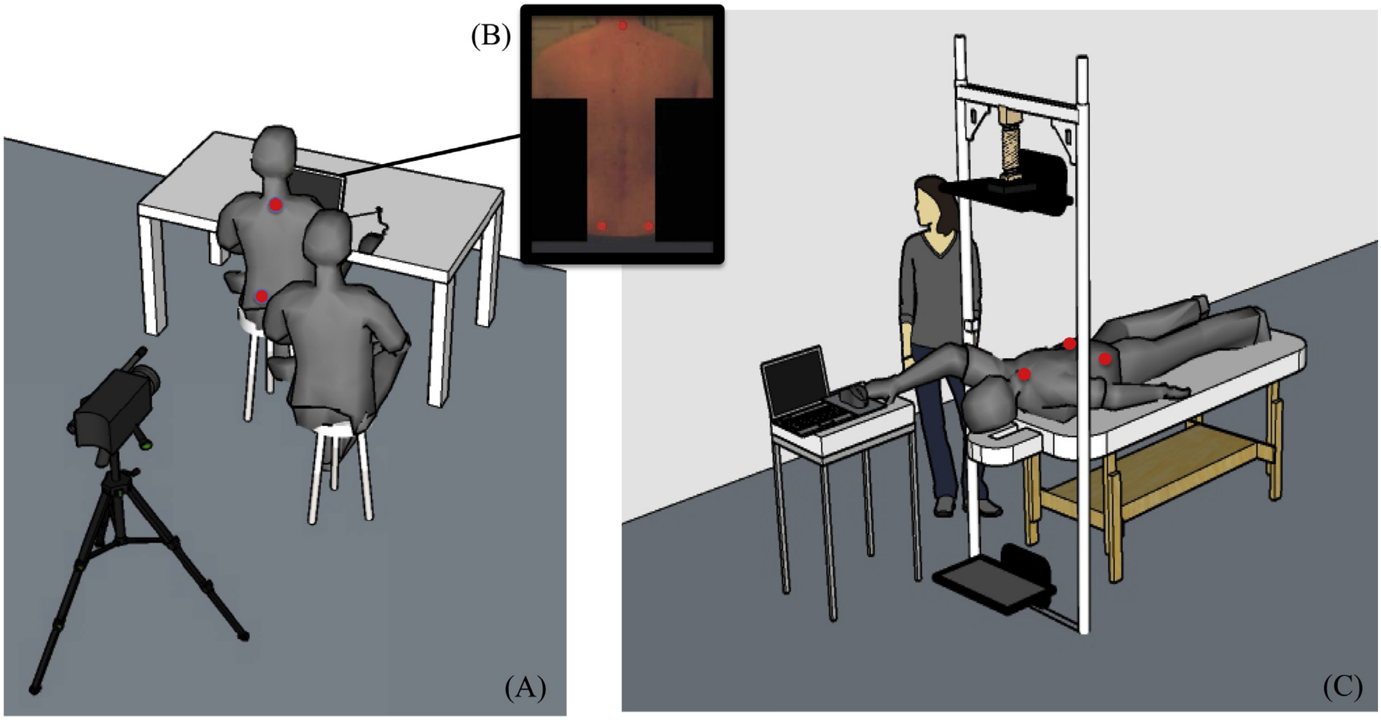

Fig 1. (A) Experimental set-up Experiment 1. (B) Image showing the participant's back with the outlines obscured, as it was presented to the participant for localization of the applied tactile stimulus. Red dots are the reference markers. Note, that the two reference markers in between the black bars were not shown to the participant, they are shown on in this figure to facilitate the understanding of data analysis. (C) Experimental set-up Experiment 2. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the *AN* group were not uniformly distributed ($R = 0.79$; $p < 0.001$) and instead centered around α_{mean} 326.60° ± 37.18°, indicating a lateral-caudal deviation (Fig. 3). At the subject level, individual Rayleigh tests revealed that most women with AN ($n = 11$) showed a systematic bias, all of them in lateral direction (e.g. participant AN04, Fig. 4).

Localization responses of the *HC* group were also not uniformly distributed, as indicated by the Rayleigh test (HC group: $R = 0.46$; $p < 0.05$). α_{mean} was 323.78° ± 52.66° in the HC group, likewise indicating a lateral-caudal deviation (Fig. 3). Most of the HC ($n = 8$) showed a systematic bias in lateral direction. (For individual results of circular statistics see supplemental material 2.)

3. Experiment 2

In Experiment 2 we investigated OPL at the back and the abdomen while participants were lying in a horizontal position. The abdomen is likely to be regarded as a highly relevant body part in terms of body dissatisfaction and emotional concern, whereas the back may be seen as a neutral body part in this respect (Keizer et al., 2012). In the context of varying emotional distress that comes with the employment of different body parts, it is of great interest to see whether OPL performance differs accordingly. The aim of Experiment 2 was therefore to extend the findings of Experiment 1 by investigating differences in OPL performance on body parts. The horizontal position was chosen in order to reduce muscle activation associated with the upright body posture, which might affect tactile processing (Medina and Coslett, 2010; Yamamoto and Kitazawa, 2001). The procedures were to a great extent identical to Experiment 1.

3.1. Methods

The study was conducted in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) and was approved by the local ethics committee of the Institute of Sports Sciences and Psychology of the University of Münster (Wagner_03_14, HW1) as well as by the Ethics Committee of the University of Münster and the Westphalian State Chamber of Physicians (2016-247-f-S).

3.1.1. Participants

Informed written consent was obtained prior to enrolment from the 52 female participants (18 women with AN, 34 HC). Participants in Experiment 2 are distinct from those of Experiment 1. The group of women with AN consisted of 17 in-patients and one women recruited by personal contacting. The data of three women with AN and four HC could not be used due to technical issues and were thus excluded from further analyses. Descriptive statistics are shown in Table 1. Information of disease duration of three patients was missing. As treatment duration differed within the AN group and treatment generally aimed at gaining weight, some women with AN ($n = 9$) no longer fulfilled the weight criterion (BMI < 17.5) for AN at the time of the study. These women can be characterized as partially remitted with regard to the BMI and are elsewhere diagnosed as patients with *Eating Disorder Not Otherwise Specified* (EDNOS; Keizer et al., 2013). It was shown that women with AN and EDNOS patients are a relatively homogenous sample (Keizer et al., 2013; Machado et al., 2007; Rodriguez-Cano et al., 2009; Williamson et al., 2002) and we therefore included the partially remitted women in our study. Diagnostic criteria and treatment approach were identical to Experiment 1. The HC group was recruited randomly via flyers at the Department of Psychology and Sports Sciences of the University of Münster as well as by personal contact. The exclusion criteria were identical to Experiment 1.

3.1.2. Procedures

The test duration for each participant was approximately 45min. The process of informing participants about study procedures was identical to Experiment 1. The experimental set-up of Experiment 2 is presented in Fig. 1C. Lying on the stretcher, the participants faced a screen, which was placed below or above the participants depending on

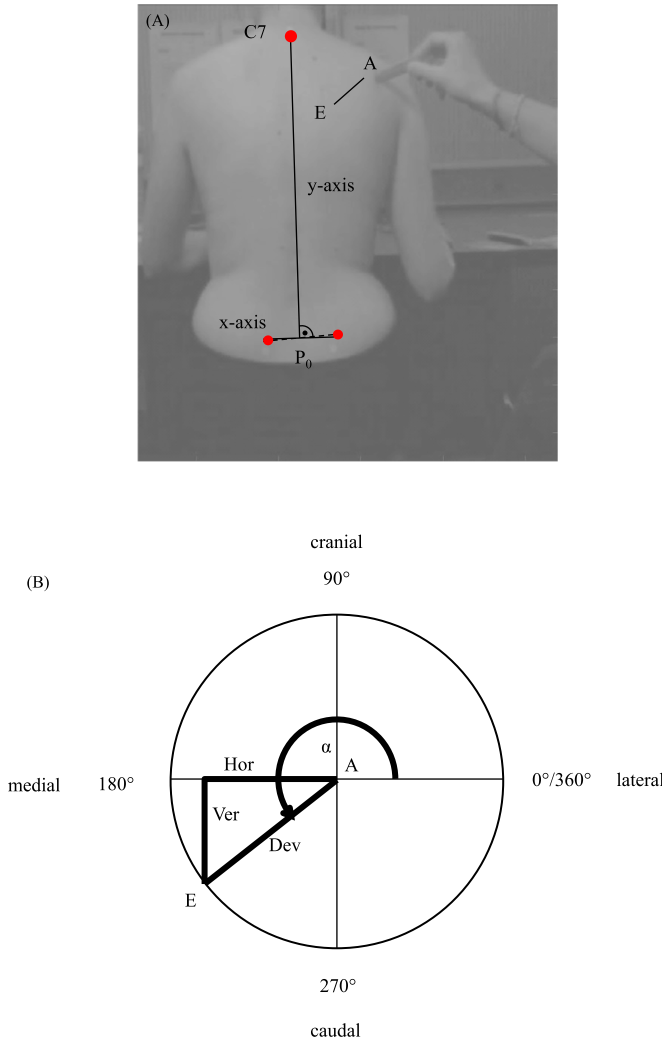

Fig 2. (A) Schematic coordinate system and applied (A) and estimated (E) tactile stimulus, superimposed on the participant's back. The origin of this coordinate system was situated at the center point (P_0) between the two markers on the fossae, with the cranio-caudal *y*-axis extending from P_0 to the C7-marker and being vertical to the *x*-axis. (B) Calculated measures of deviation: overall deviation (Dev), horizontal deviation (Hor) and vertical deviation (Ver) and direction of deviation (α) between A and E.

their position – either supine or prone. The first position was randomly chosen for each participant. Irrespective of their position, a webcam (Logitech Webcam Pro 9000 HD; 1920 × 1080 pixels) was suspended from a wooden construction directly above the stretcher, pointing straight down towards the participants' back or abdomen, respectively. Camera and screens were connected with a laptop, which captured the two photographs by a custom Matlab script and saved them for offline coding. In the supine position, the image of the abdomen was mirror-inverted. In this experiment, the abdomen and back were each divided into twelve sections – six on the right side of the body and six on the left side of the body. Tactile stimuli were applied with a van Fray hair (200 gf) ensuring that for all stimuli the same pressure was used. In each of the twelve sections, participants were stimulated three times for a total of 36 stimuli on either body part. A randomization procedure ensured that the sections were touched in a random manner. The procedure of taking photographs to save the coordinates of the actual and the estimated tactile stimulus was conducted analogously to Experiment 1. We assessed cognitive-affective body image by use of the Dresden Body Image Questionnaire (DKB-35; Pöhlmann et al., 2014).

3.1.3. *Data analyses*

Data analyses were performed using Matlab and SPSS (version 24, IBM Corp., 2016).

3.1.3.1. Overall deviation. Overall deviation was calculated in the same way as in Experiment 1 (see Section 2.1.3). In Experiment 2, the participants differed significantly with regard to their upper body length, but not in their body width. We therefore decided to normalize distances by dividing each outcome by the measured individual body width of each participant.

3.1.3.2. Direction of deviation. The direction of deviation was calculated in the same way as in Experiment 1 (see Section 2.1.3).

3.1.4. *Statistics*

3.1.4.1. Overall deviation. We conducted a two-way repeated-measures ANOVA to analyze differences with regard to overall deviation, with the between-group factor group (AN, HC) and the within-group factor body part (back, abdomen). The alpha level was set to 5%.

3.1.4.2. Direction of deviation. Identical to Experiment 1, circular statistics were used to analyze direction and distribution of data (for more information see Section 2.1.4).

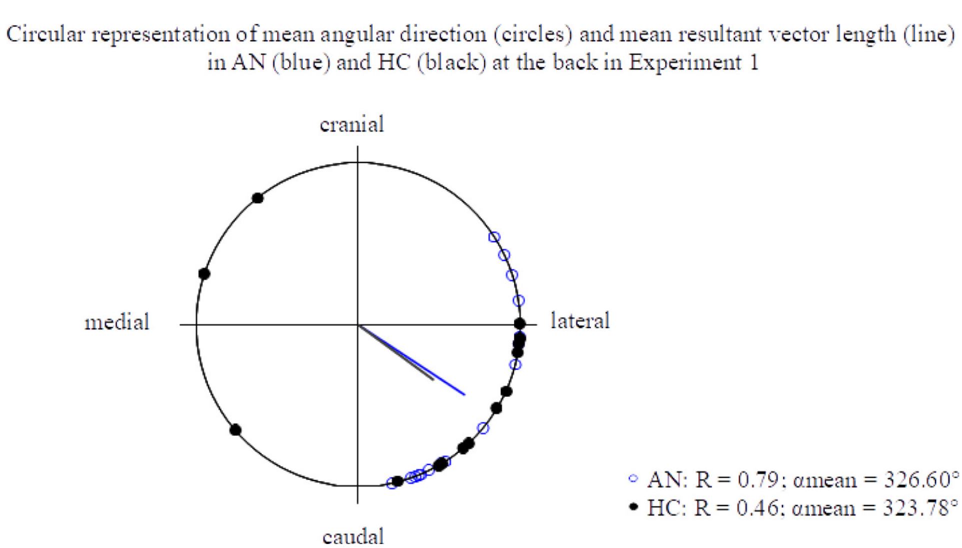

Fig 3. Blue circles are the mean angular direction (α_{mean}) of each participant of the group of 14 women with Anorexia Nervosa (AN) and two women with atypical AN and black circles are α_{mean} of each participant of the healthy control (HC) group. The two lines (blue = AN; black = HC) indicate the mean resultant vector lengths (R) of both groups. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

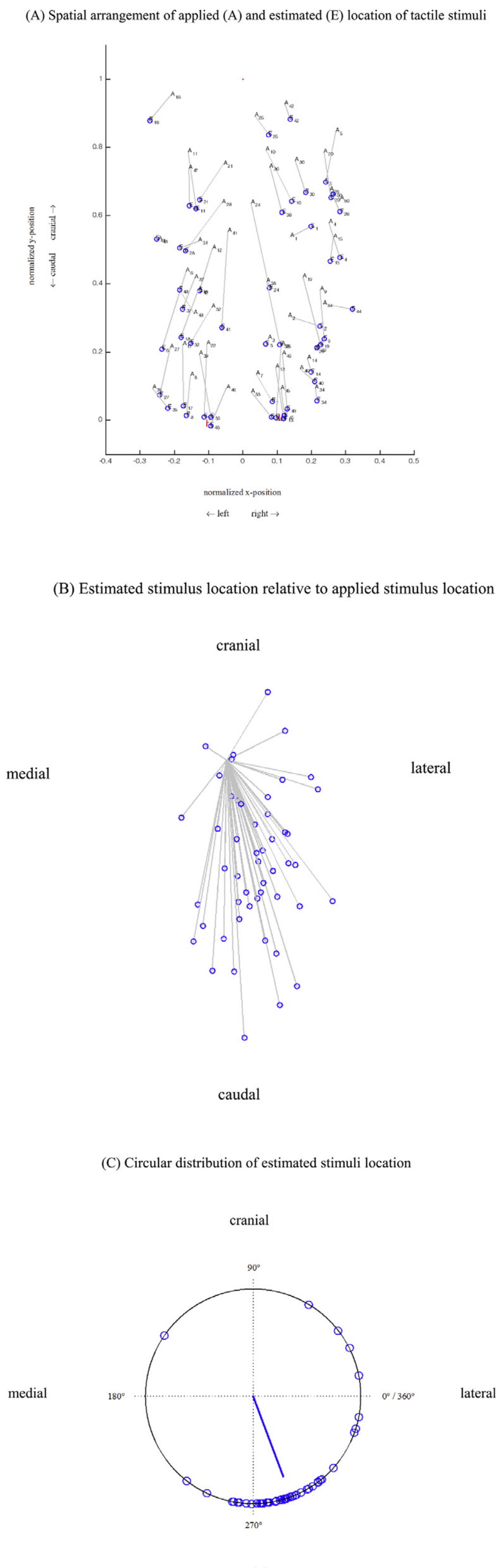

Fig 4. Data of one participant of the group of women with Anorexia Nervosa (AN) at the back in Experiment 1. (A) A line is plotted to connect the applied (A) and the estimated (E, blue circles) stimulus location. Red dots are the reference marker. (B) All 50 estimated stimuli locations (blue circles) are plotted relative to the applied tactile stimulus. (C) Estimated stimuli locations (blue circles) are plotted on a circle. The mean resultant vector length ($R = 0.80$; blue line) is plotted in the direction of the mean angular direction of this participant ($\alpha_{mean} = 290.54°$). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

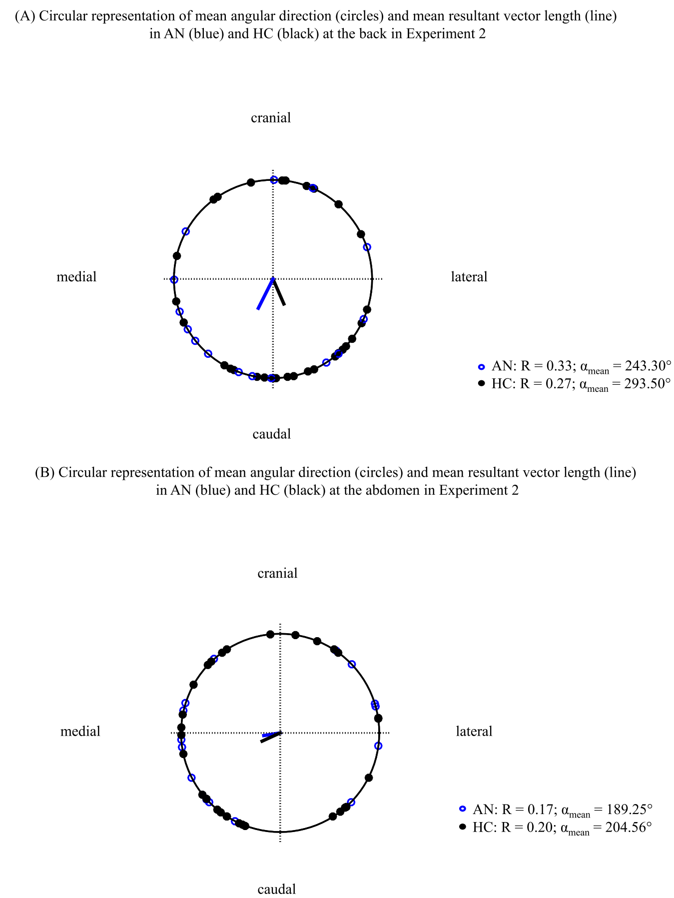

Fig 5. Blue circles are the mean angular direction (α_{mean}) of each participant of the group of six women with acute Anorexia Nervosa (AN) and nine partially remitted women with AN and black circles are α_{mean} of each participant of the healthy control (HC) group. The two lines (blue = AN; black = HC) indicate the mean resultant vector length (R) of both groups. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3.2. Results

3.2.1. Overall deviation

The AN group's overall deviation was slightly higher both at the back ($Dev_{AN} = 0.24 \pm 0.12$; $Dev_{HC} = 0.20 \pm 0.11$) and the abdomen ($Dev_{AN} = 0.23 \pm 0.12$; $Dev_{HC} = 0.22 \pm 0.12$) compared to the HC group. This effect was not significant ($F(1,43) = 0.47$; $p = 0.499$; $\eta_p^2 = 0.01$). Furthermore, there were no significant differences between the two body parts ($F(1,43) = 0.06$; $p = 0.812$; $\eta_p^2 < 0.01$). (For results of horizontal and vertical deviation see supplemental material 1.)

3.2.2. Direction of deviation

The *AN* group showed a uniform distribution at the *back* ($R = 0.33$, $p = 0.197$; α_{mean}: $243.30° \pm 66.33°$; Fig. 5A). Twelve participants of the AN group showed a systematic bias: seven women with AN showed a systematic bias in medial direction and five showed a systematic bias in lateral direction at the back.

The *HC* showed a uniform distribution at the *back* ($R = 0.27$, $p = 0.105$; α_{mean}: $293.50° \pm 69.04°$, Fig. 5A). Nine participants of the HC group showed a systematic bias, five of them in lateral direction and the remaining four in medial direction.

Generally, the group of women with AN showed a uniform distribution ($R = 0.17$; $p = 0.665$; α_{mean}: $189.25° \pm 73.94°$; Fig. 5B) at the *abdomen*. However, eight participants showed a systematic bias, four in medial and lateral direction each.

The *HC* showed a uniform distribution at the *abdomen* ($R = 0.20$; $p = 0.302$; α_{mean}: 204.56° ± 72.45°; Fig. 5B). Eleven participants of the control group showed a systematic bias, only three of them in lateral direction, all others in medial direction. (For individual results of circular statistics see supplemental material 2.)

4. Discussion

The aim of the two experiments in the present study was to investigate if the mapping of a tactile stimulus onto a visual presentation of the body is altered in women with AN. We hypothesized there would be a greater overall deviation between actual and estimated location of touch (hypothesis 1) and a systematic bias in lateral direction in the AN group (hypothesis 2). Furthermore, it was hypothesized that differences are stronger at the abdomen (hypothesis 3).

The analyses of the magnitude of deviation revealed that women with AN and HC did not differ in their ability to accurately localize the stimulus (hypothesis 1). Neither did we find group differences between performance at the back and the abdomen (hypothesis 3). Both groups deviated systematically in a lateral-caudal direction in Experiment 1, but did not show any systematic bias in Experiment 2 (hypothesis 2). Thus, our hypotheses pertaining to group differences were largely unconfirmed.

However, beside the results of the analyses for the whole groups, even more relevant seem to be the individual results: nearly all of the women with AN ($n = 31$) and almost 2/3 of the HC ($n = 28$) showed systematically distorted perceptions across both experiments and for at least one body part. That is, even though there was a uniform distribution within the groups (in Experiment 2) in terms of the direction of deviation, at the individual level a substantial number of participants showed a specific mean direction indicating a systematic bias. However, this bias was not consistently directed to the lateral side.

The finding of systematically distorted representations, even in healthy individuals, is in line with other studies, which have revealed distorted body representations across a wide range of tasks (for review see Longo, 2015). The studies investigated body representations underlying proprioception (e.g. Fuentes et al., 2013; Longo and Haggard, 2010), nociception (e.g. Mancini et al., 2011; Trojan et al., 2006) and touch (e.g. Steenbergen et al., 2012). Beside studies investigating tactile size perception (e.g. Longo and Haggard, 2011) also tactile localization tasks (e.g. Longo, 2015; Mancini et al., 2011; Margolis and Longo, 2014; Steenbergen et al., 2012) have been used to investigate the perception of the size and shape of body parts. Longo (2015) investigated the perception of hand and finger size based on position sense (i.e. proprioception), tactile size perception and tactile localization and found that participants perceived their hands and fingers wider and shorter than they really are. The author explains these results with regard to distortions in the body model and the superficial schema, respectively. However, this assumption has previously been questioned by a study from Medina and Duckett (2017). Notably, most of these studies' results refer to the entire sample indicating that systematic biases generally occur across groups as a whole. In Experiment 2, no systematic biases across the group were found. Interestingly, Steenbergen et al. (2012) did also not find a common pattern of localization for all individuals (i.e. the group). However, in their study tactile and nociceptive stimuli were included.

A number of studies suggested that the distorted body image in AN does not reflect a real perceptual deficit, but is either driven by methodological problems when using BSE tasks (Meermann et al., 1986) or by patients' negative attitudes towards their body (Hennighausen et al., 1999; Mölbert et al., 2018). As for the latter, this would characterize the body image disturbance more as a cognitive-affective disturbance, rather than a genuine perceptual impairment. In this study, we neither found differences in overall deviation between the groups nor between the back and the abdomen. One explanation we offer is that focusing on the localization instead of on a body size or (tactile) distance estimation indeed minimizes cognitive-affective influences. Even though the women with AN had a significantly worse cognitive-affective body image (see Table 1; for further information regarding DKB-35 see supplemental material 3) compared to HC, this was not reflected in a difference in their OPL performance.

Besides methodological problems using BSE tasks there might be a general bias of overestimating tactile distances pertaining to the body when tactile distance estimations are assessed (Keizer et al., 2011). This would imply that it is not only the implicit character of the OPL task that accounts for the result that women with AN and HC perform more or less equivalently, but that it is the missing estimation of metric properties (i.e. distances) pertaining to the body. In short: when visuo-tactile processing is not affected by top-down influences by confronting women with AN with body silhouettes or metric body properties, OPL performance in women with AN did not rely on a wider body representation. Therefore the results of this study support the idea that the overestimation in women with AN found in previous studies is due to cognitive-affective aspects as for example body dissatisfaction rather than to perceptual deficits. It appears that visual and tactile information processing is task-dependent (Kammers et al., 2010). In other words, distorted body representations in AN only come to the fore in certain tasks.

Given the relatively small sample size of 31 participants (16AN, 15HC) in Experiment 1 and 45 participants (15AN, 30HC) in Experiment 2 and non-significant group differences, we conducted post hoc power analyses using G*Power (Faul et al., 2007) with $\alpha = 0.05$, two-tailed and an effect size of Cohen's $d = 0.5$ in Experiment 1 and $\eta_p^2 = 0.01$ in Experiment 2. Results of power calculations revealed a low power (1-ß) of 0.26 and 0.55 for both studies, respectively. Power analyses additionally revealed that in order for the effects of these sizes (see above) to be detected (80% chance) as significant at the 5% level, a total sample of $n = 134$ in Experiment 1 and $n = 80$ in Experiment 2 would be required. Thus, the possibility still remains that due to a lack of power significant results could not have been detected. However, it has to be noted here, that the sample size in our study is in line with other studies investigating body perception in women with AN (Keizer et al., 2013, 2012; Spitoni et al., 2015; Zucker et al., 2013). Besides increasing the sample size, one way to increase statistical power is by increasing the effect size. At this time, however, we are not aware of any obvious (methodological) adjustments that would achieve this. Instead, the results showed that there is no trend of women with AN performing differently compared to HC when cognitive-affective influences are minimized. This assumption is also in line with other studies (e.g. Mölbert et al., 2018; Waldman et al., 2013).

Although it still remains unresolved as to what specific factors play a role in the differences in perceptual biases between (i.e. also in-between the groups) and within (i.e. between body parts) individuals, this study has shown that OPL can be a promising paradigm to systematically investigate distorted perception. Note here that the different distorted perceptions can be due to distortions in the somatotopic map, the transformation from this map to the representation containing information about body outlines or the mapping of the perceived stimulus onto the visual representation of the body. What we assess in our task is the net effect of these potential distortions. Furthermore, the combination of visual and tactile stimuli makes it difficult to disentangle the particular contribution each modality made on its own to the outcome of the OPL task. Hence, even if unlikely with regard to the previously reported results of BSE studies and tactile perception studies, it may be possible that visual and tactile misperceptions were directed into opposite directions (e.g. visually overestimating the body outlines and showing tactile disturbances directed to the body midline) and thus cancelled each other out. In that case, participants would appear to perform well although they were actually guided by inversely directed misperceptions. In this context, it would be interesting to investigate the effect of visual information on performance on the OPL task. For instance, showing the participants' shoulders (Fig. 1B) might give such accurate visual information that it would offset any distorted tactile representation. This is particularly interesting as it was shown that visual information may influence tactile localization (Margolis and Longo, 2014) and that women with AN rely more on visual information than on other modalities, and more so than HC (Eshkevari et al., 2012).

We believe it is important that future research efforts try to further a) disentangle the role of cognitive-affective and perceptual influences on body size perception in AN, for example by validating existing and developing new measurements of BSE, b) investigate distorted perception based on localization tasks in different samples and on different body parts and c) elaborate on the role of integrating different sensory input and its relation to different body representations. Besides studies which try to investigate body representations on a behavioral level, neuro-imaging studies might help to understand underlying brain mechanisms during body (size) perception and visual and tactile information processing. For example, it was shown that women with AN show atypical patterns of activation in parietal regions of the cortex, a region linked to somatosensory processing and the formation of body representations (Kojima et al., 2005; Nico et al., 2010; Wagner et al., 2003). Further, neuroimaging techniques might help to specify and quantify cognitive-affective influences on body size perception in AN, which is still one of the most challenging research questions in the context of body image disturbance in AN.

Declaration of interests

All authors declare no conflict of interest.

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Supplementary materials

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