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

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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.

Thirty AN patients and thirty 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 in the experimental, but not the control condition. AN patients and HC did not differ on proprioceptive drift. Before induction of the illusion AN patients overestimated hand 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 under both experimental and control conditions 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 (APA, 2000). This is traditionally referred to as a disturbance in body image. The literal "image" of the body, i.e. how AN patients visually perceive themselves, has been investigated extensively in previous research (see e.g. Cash & Deagle, 1997; Farrell, Lee, & Shafran, 2005; Skrzypek, Wehmeier, & Remschmidt, 2001; Smeets, Smit, Panhuysen, & Ingleby, 1997). Many studies have shown that AN patients visually overestimate their body size compared to healthy controls (e.g. Cash & Deagle, 1997; Skrzypek et al., 2001; Smeets et al., 1997), although other authors have failed to reach this conclusion (e.g. Cornelissen, Johns, & Tovee, 2013; Farrell et al., 2005).

In recent years an increasing number of researchers has taken an interest in understanding the disturbed experience of body size in AN from a neuro(psycho)logical viewpoint (e.g. Faris et al.,1992; Friederich et al.,2010; Grunwald et al., 2001, 2002; Guardia, Cottencin, Thomas, Dodin, & Luyat, 2012; Miyake et al., 2010; Mohr et al., 2010; Nico et al., 2010; Suchan et al., 2010; Wagner, Ruf, Braus, & Schmidt, 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 also extends to altered performance on tasks involving tactile perception (e.g. Keizer et al., 2011; Keizer, Smeets, Dijkerman, van Elburg, & Postma, 2012), haptic perception (e.g. Grunwald et al., 2001, 2002; Guardia, Cottencin, et al., 2012) as well as action-oriented tasks (e.g. Guardia, Cottencin, et al., 2012, 2010; Keizer et al., 2013; Nico et al., 2010). Thus it appears that body (size) representation disturbances can be identified in multiple modalities, which underlines its central role in AN pathology. What is yet unclear is whether this disturbed body representation can be experimentally manipulated. This is an important question as current treatment

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approaches focusing on the disturbed experience of body size in AN have not been very successful (e.g. Exterkate, Vriesendorp, & de Jong, 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. Several studies have for example shown that multisensory bodily illusions can be used to modulate the experienced size of different body parts in healthy populations (see e.g. Kilteni, Normand, Sanchez-Vives, & Slater, 2012; Normand, Giannopoulos, Spanlang, & Slater, 2011; Preston & Newport, 2012; van der Hoort, Guterstam, & Ehrsson, 2011)

Eshkevari, Rieger, Longo, Haggard, and Treasure (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 receive synchronized tactile stimulation (see e.g. Botvinick & Cohen, 1998; Ehrsson, Spence, & Passingham, 2004; Kammers, de Vignemont, Verhagen, & Dijkerman, 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 own 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 & Cohen, 1998). The strength of the illusion is measured on a subjective self-report level with a questionnaire (see e.g. Longo, Schuur, Kammers, Tsakiris, & Haggard, 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 & 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 et al. (2012) concluded that a stronger experience of the illusion in AN patients indicates 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 enhanced visual capture. In other words, characteristics inherent to AN might facilitate a 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 under both synchronous and asynchronous (control) conditions, implying AN patients' excessive focus on visual information.

Interestingly, just as other multisensory bodily illusions (see e.g. Kilteni et al., 2012; Normand et al., 2011; Preston & Newport, 2012; van der Hoort et al., 2011), 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 & 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 & Jundi, 2009). This is in accordance with reports of Longo et al. (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., 2008). In addition Longo, Schuur, Kammers, Tsakiris, and Haggard (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 & 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. From our clinical observations it may be inferred that patients 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 et al. (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., 2012; Sachdev, Mondraty, Wen, & Gulliford, 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., 2012; Slade & 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 showing an increase in size estimation of the rubber hand after induction of the RHI compared to before induction of the RHI, as it is no longer an external object, but part of the own body. However, would the change in ownership over the rubber hand (i.e. not mine vs. mine) also affect the experience of *actual*, own, 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.

At first glance the hypothesis suggesting a decrease in size estimation of the own hand seems unlikely. Several studies using bodily illusions other than the RHI in healthy populations have shown that it is possible to induce an illusionary *enlargement* of the size of a body part (e.g. Kilteni et al., 2012; Normand et al., 2011; Preston & Newport, 2012). In line with this, a study using an adapted version of the RHI indicated a stronger illusion when a large fake hand was used (Pavani & Zampini, 2007). It has been suggested that it is more difficult to induce illusionary *shrinkage* of body part size with multisensory bodily illusions (e.g. Pavani & Zampini, 2007). This may for example be related to normal development: From infancy to adulthood the body of an individual usually grows, while throughout the lifespan shrinkage is less common. It should however be noted that for example a vibrotactile bodily illusion *can* result in illusionary shrinkage of the size of for example the nose (Lackner, 1988) or waist (Ehrsson, Kito, Sadato, Passingham, & Naito, 2005). More importantly, these previous studies have not focused on populations who by definition have a disturbed experience of the size of their own body. We do not aim to induce the RHI using larger and smaller fake hands, as did for example Pavani and Zampini (2007). We are instead interested in whether inducing the RHI with a normal-sized hand affects subsequent size estimation of the rubber and own hand differently in AN patients and healthy females. Therefore, following the line of reasoning that after induction of the RHI the size of the rubber hand is incorporated into the mental representation of the body (e.g. Haggard & Jundi, 2009; Longo et al., 2009; Moseley et al., 2008), 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. In the current study this would result in hypothesizing that AN patients will correct their assumed initial overestimation of hand size, i.e. size estimations of their own hand would be expected to decrease and more closely resemble actual hand size.

We were also interested in pleasantness ratings of tactile stimulation. From a clinical perspective this is interesting as most AN patients are not comfortable being touched. We wanted to ensure that the touching of the hand of the patients in itself did not bias the RHI effects because it was experienced as unpleasant. By asking participants to rate pleasantness of the tactile stimulation we were able to control for possible group differences on this measure. In addition, the insula plays an important role in assigning emotional valence to sensory input (see e.g. Craig, 2002, 2009) and it has been suggested that insular functioning is altered in AN patients compared to healthy individuals (see e.g. Nunn, Frampton, Fuglset, Torzsok-Sonnevend, & Lask, 2011; Strigo et al., 2013). The insula has also been implicated to be involved in bodily awareness (see e.g. Baier & Karnath, 2008; Tsakiris, 2010) and affective touch can influence bodily awareness as assessed by the RHI (Crucianelli, Metcalf, Fotopoulou, & Jenkinson, 2013; van Stralen et al., 2014).

2. Methods

2.1. Participants

The current study was approved by two independent ethics committees (Medical Ethical Committee University Medical Centre Utrecht and the Committee Scientific Research of Altrecht Mental Health Institute). The study adhered to the tenets of the Declaration of Helsinki 2013. 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 was obtained from the participant.

Sixty females participated on the basis of written informed consent. The healthy control group consisted of 30 healthy females. The AN patient group consisted of a total of 30 patients, 20 AN patients and 10 eating disorder not otherwise specified (EDNOS) patients. Patients were recruited from Rintveld Centre for Eating Disorders, Altrecht Mental Health Institute in Zeist. Here patients received treatment as usual ranging from daily to weekly sessions aimed at cognitive improvement and weight restoration. 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”.

Participants were screened on several inclusion and exclusion criteria. Participants from both groups were required to be at least 18 years old and not have a physical condition that prevented them from performing the experiment (e.g. arm injuries or skin conditions on the hand). AN group specific inclusion criteria were an (initial) AN diagnosis or EDNOS diagnosis with clinical characteristics of AN, which was verified using the Eating Disorder Inventory-2 ((EDI-2) Garner, 1991) and the patient file. HC specific inclusion criteria were a healthy Body Mass Index (BMI; i.e. between 19 and 25) (initially based on self-report, height and weight were measured during the experiment by the experimenter to verify self-reported BMI) and no history of or current psychiatric disorder, substance/alcohol abuse, or medical illness (based on self report). Using the EDI-2, HC were specifically screened for the presence of an eating disorder. Exclusion criteria for both groups were use of medication that could influence task performance due to e.g. drowsiness, sedative effects, or (psycho)motoric impairments (e.g. benzodiazepines, anti-epileptic medication).

Four AN patients were left-handed, as were six HC. Mean age for AN patients was 26.37 (SD=9.08) and 21.80 (SD=2.37) for HC, $t(32.93)=2.67$, $p=.010$. Age did not correlate with any of the variables of interest (see Supplementary Tables). Mean

Table 1
Demographic and clinical characteristics of the AN group opposed to HC group.

	AN group ($n=30$)		HC group ($n=30$)				
	M	SD	*M*	SD	*t*	df[a]	*p*
Age	26.37	9.08	21.80	2.37	2.67	32.93	.010
BMI	17.50	2.14	21.19	2.01	−6.91	58	<.001
BAT[b]	60.03	18.55	25.10	9.00	9.28	41.92	<.001
EDI-2 total score[c]	246.13	44.46	154.60	28.39	9.50	49.28	<.001
EDI-2 DT[c]	32.97	6.77	16.60	6.61	9.47	58	<.001
EDI-2 BD[c]	42.40	9.60	26.30	7.68	7.17	58	<.001
EDI-2 IA[c]	36.37	8.02	20.20	5.54	9.09	58	<.001
SOQ[d]	5.73	9.80	−3.43	12.59	1.15	58	.003
DASS total[e]	27.30	12.37	7.90	5.14	7.93	38.73	<.001
DASS depression[e]	9.03	5.01	1.73	1.78	7.52	36.20	<.001
DASS anxiety[e]	6.30	3.83	1.90	1.97	5.59	43.33	<.001
DASS stress[e]	11.97	5.14	4.27	3.29	6.92	49.37	<.001
BMI at intake	15.85	2.05	n/a	n/a	n/a	n/a	n/a
Fat percentage at intake	9.41	7.08	n/a	n/a	n/a	n/a	n/a
Illness duration (in months)	11.70	17.56	n/a	n/a	n/a	n/a	n/a

[a] df for the independent samples *t*-tests vary due to significance of Levene's test for some variables.
[b] BAT refers to Body Attitude Test (Probst, Vandereycken, Van Coppenolle, & Vanderlinden, 1995).
[c] EDI-2 refers to Eating Disorder Inventory 2 (Garner, 1991); EDI-2 DT refers to EDI-2 Drive for Thinness subscale; EDI-2 BD refers to EDI-2 Body Dissatisfaction subscale; EDI-2 IA refers to EDI-2 Interoceptive Awareness subscale.
[d] SOQ refers to Self-Objectification Questionairre (Noll & Fredrickson, 1998).
[e] DASS refers to Depression Anxiety Stress Scale (Lovibond & Lovibond, 1995).

(BMI) was 17.50 (SD=2.14) for AN patients and 21.19 (SD=2.01) for HC, $t(58) = -6.91$, $p < .001$. As AN patients by definition have a lower BMI than HC, we could not match the two participant groups on BMI. Including this variable in the analyses enabled us to control for differences in BMI, in case BMI would correlate with any of the relevant variables. Mean disease duration for AN patients was 11.7 months (SD=12.95), note that patients may have received treatment elsewhere as well. Other clinical characteristics of the AN group are shown in Table 1.

2.2. Rubber hand illusion

2.2.1. Embodiment questionnaire

The Embodiment Questionnaire (EQ) (based on Botvinick & Cohen, 1998; Kammers et al., 2009) assessed the subjective experience of the RHI by letting participants rate 10 statements on a 10-point Likert-scale ranging from 1 "I strongly disagree" to 10 "I strongly agree" (see Table 2 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 & Cohen, 1998; Kammers et al., 2009). The remaining seven statements are often included as "control" questions and provide additional information on individual illusion experience, such as vividness (see e.g. Kammers et al., 2009). 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 rating on each EQ item over the two synchronous inductions as well as the average over the two asynchronous inductions.

2.2.2. Proprioceptive drift

To measure proprioceptive drift, the experimenter moved a vertical 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 reflects 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 and asynchronous (control) conditions 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.

2.2.3. 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 s, 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. Under 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. As the synchronous and asynchronous (control) conditions of the RHI were both induced twice in the current experiment, in analyses we used the average size estimation over the two synchronous inductions as well as the average over the two asynchronous inductions.

2.3. Procedure

For a schematic overview of the procedures, see Fig. 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 Botvinick and Cohen (1998) and Kammers et al. (2009). On the desk stood a wooden box (77.5 × 50.0 × 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 left hand from view while the rubber hand remained visible (see Fig. 2A). The box could be closed off by placing a board on top (see Fig. 2B). While their hands were placed in their lap, so they could not be seen, participants viewed the rubber hand for 30 s. 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.

With the board still on top of the box, a black cloth was placed over the shoulder and arm of 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 Fig. 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 (i.e. stroked with a soft brush) the rubber and actual hand, and twice asynchronously (control condition). The order of these conditions was counterbalanced. The direction of stroking was under the synchronous as well as asynchronous (control) condition always towards the fingertip (starting on the top of the hand, just above the knuckle), with a speed of approximately 1 stroke per second. Under the synchronous condition the timing of stroking was simultaneous, while Under the asynchronous condition the timing of stroking was out of sync by 180°. In other words, under the asynchronous condition stroking on one hand was "echoed" on the other hand, and the actual hand and rubber hand were never touched by the brush at the same time.

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. Participants opened their eyes and the experimenter stroked the rubber hand and actual hand with a soft brush for 90 s. 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 10-point Likert scale ranging from 1 "very unpleasant" to 10 "very pleasant". The experiment 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 were used.

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 2.

Scores above "5" (neutral) are indicative of an affirmative response. Generally the first three statements are used to measure the strength of the experience of ownership over the rubber hand, while the other statements are regarded as control questions or questions assessing for example how vivid participants experienced the illusion (see e.g. Kammers et al., 2009). Note that high scores (above "5" (neutral)) on these control questions can also be indicative of a general tendency to give higher ratings on questionnaires due to task compliance of suggestibility effects, a factor that should be taken into account when (psychiatric) patients are tested. Therefore we created two subscales. One including items specifically related to experiencing the illusion, and one including "control" items on which participants are not expected to score high, irrespective of them experiencing the illusion or not. Using the mean rating of the first three statements we constructed the "Ownership subscale". The higher the mean score, the more strongly the participant experienced ownership over the rubber hand. The remaining (control) items (mean rating of statements 4–10) were grouped together on the "Control subscale". Both subscales had a minimum score of zero and a maximum score of 10.

Data for the separate questions and the subscales was not always normally distributed. Specifically, in the AN group data for the ownership subscale under the synchronous condition was not normally distributed (Shapiro–Wilk(30)=.843, $p<.001$), the other subscales were normally distributed for AN patients ($\text{Shapiro–Wilk}_{\text{control subscale sync}}(30)=.970$, $p=.547$; $\text{Shapiro–Wilk}_{\text{ownership subscale async}}(30)=.966$, $p=.437$; $\text{Shapiro–Wilk}_{\text{control subscale async}}(30)=.976$, $p=.726$). In the HC group all subscales were not normally distributed ($\text{Shapiro–Wilk}_{\text{ownership subscale sync}}(30)=.872$, $p=.002$; $\text{Shapiro–Wilk}_{\text{ownership subscale async}}(30)=.921$, $p=.029$; $\text{Shapiro–Wilk}_{\text{control subscale async}}(30)=.860$, $p=.001$), except for the control subscale under the synchronous condition (Shapiro–Wilk(30)=.935, $p=.068$). We performed non-parametric tests to compare the different subscales when one or both of the relevant variables was not normally distributed. Only the control subscale under the synchronous condition was normally distributed in both the AN and HC group, this difference was tested parametrically with an independent samples *t*-test.

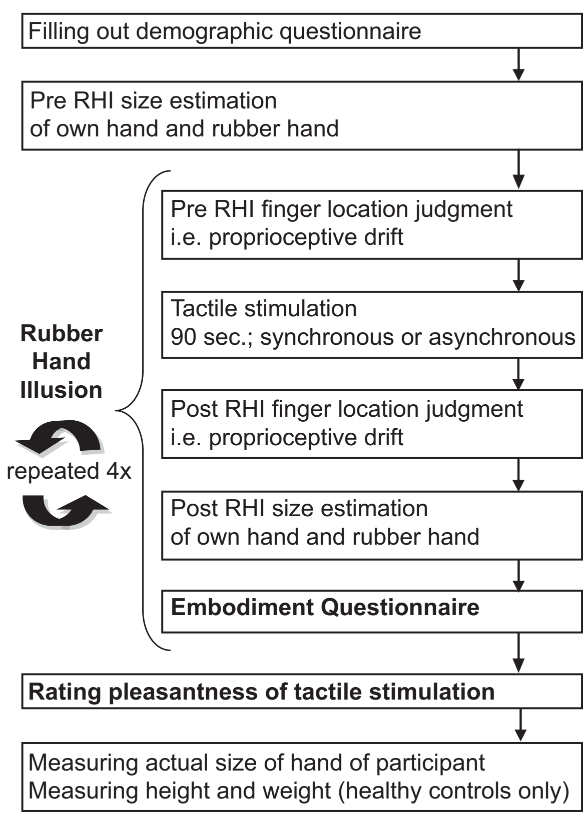

Fig. 1. Schematic depiction of the experimental procedures.

Bonferroni corrected Pearsons correlations (critical $p=.001$), see Supplementary Tables, showed no correlation between the EQ subscales and BMI under the synchronous and asynchronous conditions for the AN and HC group, therefore we did not control for BMI in analyses.

First, as Table 2 shows, the illusion was successfully induced in both AN group and HC group: Both groups rated statement 1–3 as above "5" (neutral) under the synchronous condition, and below "5" (neutral) under the asynchronous condition. In other words, under the synchronous condition participants experienced ownership over the rubber hand, while they did not under the asynchronous condition. As for the subscales, only on the ownership subscale the statements were on average rated as above "5" (neutral). For AN patients the mean rating on the ownership subscale was 7.96 (SD=2.04) under the synchronous condition and 4.08 (SD=2.23) under the asynchronous condition. For HC mean ownership subscale score was 6.59 (SD=2.65) under the synchronous condition and 3.42 (SD=1.88) under the asynchronous condition. For AN patients the mean rating on the control subscale was 4.64 (SD=2.25) under the synchronous condition and 3.82 (SD=2.02) under the asynchronous condition. For HC mean control subscale score was 3.73 (SD=1.71) under the synchronous condition and 3.12 (SD=1.81) under the asynchronous condition, see also Fig. 3 and Table 3.

We first tested whether AN patients and HC differed on the ownership subscale using Bonferroni corrected Mann–Withney U tests (critical $p=.025$). The results showed that under the synchronous condition AN patients and HC differed, with AN patients having a stronger experience of ownership over the rubber hand than HC, MWu=298.50, $Z=-2.24$, $p=.025$, Cohen's $d=.58$. Under the asynchronous condition no group difference was found, MWu=357.50, $Z=-1.37$, $p=.171$, Cohen's $d=.32$. Second, even though scores below "5" (i.e. neutral) on the control subscales imply that participants did not respond affirmative to the control questions of the EQ (i.e. did not experience the illusion), we checked whether AN patients and HC differed on the control subscale using Bonferroni corrected independent samples *t*-test and Mann–Whitney U test (critical $p=.025$). As Table 3 shows, group differences were found neither in the synchronous ($t(58)=1.78$, $p=.080$, Levene's $F=1.32$, $p=.255$, Cohen's $d=.45$) nor under the asynchronous condition (MWu=343.50, $Z=-1.58$, $p=.115$, Cohen's $d=.37$).

Taken together the results of the EQ show that AN patients had a stronger experience of ownership over the rubber hand than HC under the synchronous (experimental) condition, which is also reflected by a higher effect size. AN patients and HC did not differ on statements that may be regarded as control questions, which makes it unlikely that a stronger subjective experience of ownership in the AN group resulted from e.g. a general tendency to respond

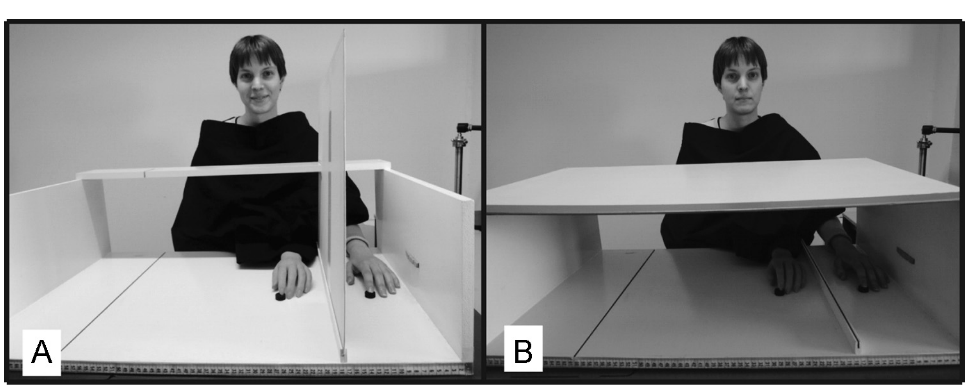

Fig. 2. Panel A depicts the Rubber Hand Illusion (RHI) set-up with a vertical board, occluding only the actual hand (the hand on the far right in the picture) from view. Panel B depicts the RHI set-up with a horizontal board, occluding both rubber hand and actual hand from view.

Table 2
Statements, mean ratings and SD's on the Embodiment Questionnaire by condition and group. Results for Bonferroni corrected Wilcoxon singed ranks tests and paired samples *t*-tests (critical $p = .005$) are reported below.

	AN patients ($n=30$)						HC ($n=30$)					
	Synchronous		Asynchronous				Synchronous		Asynchronous			
	M	SD	*M*	SD	*Z*	*p*	*M*	SD	*M*	SD	*Z*	*p*
1. It seemed as if I was feeling the touch at the location where I saw the rubber hand being touched	8.68	2.02	4.28	2.68	−4.60	.000	7.50	2.84	3.58	2.23	−4.48	.000
2. It seemed as though the touch I felt had caused the stimulation on the rubber hand	8.07	2.11	3.83	2.27	−4.55	.000	6.60	2.77	3.33	2.03	−4.43	.000
3. I felt as if the rubber hand was my own hand	7.12	2.65	4.12	2.70	−4.34	.000	5.68	2.79	3.35	2.07	−3.85	.000
4. It felt as if my real hand was drifting towards the rubber hand	5.25	2.66	3.70	2.55	−3.08	.002	3.78	2.34	2.97	2.15	−2.31	.021
5. It felt as if I had more than one left hand	2.30	1.94	2.38	1.68	−.15	.878	2.02	1.42	1.87	1.33	−.93	.352
6. It seemed as if the touch I was feeling came from in between my own hand and the rubber hand.	3.17	2.37	2.62	1.88	−2.03	.042	2.27	1.52	2.55	1.98	−.41	.685
7. It felt as if my real hand was turning “rubbery”	3.57	2.59	2.95	2.04	−1.80	.072	3.07	2.36	2.45	1.94	−2.31	.021
8. It appeared (visually) as if the rubber hand was drifting towards my own hand	3.30	2.51	3.03	1.82	−.62	.536	2.30	1.70	2.13	1.52	−.93	.351
9. The rubber hand began to resemble my own real hand, in terms of shape, skin tone, freckles, etc.	5.15	3.16	4.27	2.57	[a]2.95	.006	4.85	2.57	3.33	1.85	−2.99	.003
10. It felt as if the rubber hand and my own hand lay closer together	5.15	2.98	3.95	2.48	[a]2.95	.006	4.08	2.17	3.43	2.28	−1.96	.050

[a] Only in the AN group data for responses on EQ9 en EQ10 was normally distributed under both synchronous (Shapiro–Wilk$_{EQ9}$(30)=.93, $p=.056$; Shapiro–Wilk$_{EQ10}$(30)=.94, $p=.083$) and asynchronous conditions (Shapiro–Wilk$_{EQ9}$(30)=.96, $p=.274$; Shapiro–Wilk$_{EQ10}$(30)=.95, $p=.173$). We performed Bonferroni corrected paired samples *t*-tests (critical $p=.005$) for these two items in the AN group (df=29), *t* values are reported in the “*Z*” column.

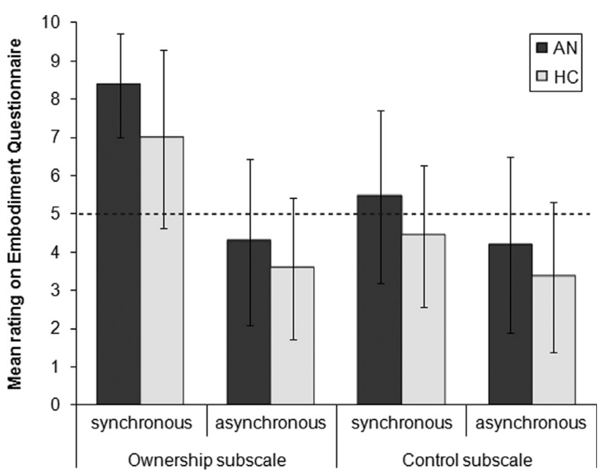

Fig. 3. Mean scores on ownership and control subscales of the Embodiment Questionnaire by condition and group. The dashed line at 5 represents a “neutral” response.

Table 3
Mean ratings and SD's on the EQ subscales by condition and group. Cronbach's alpha is reported for each subscale. Results for Bonferroni corrected Mann–Whitney U tests and an independent samples *t*-test on group differences under the synchronous condition (critical $p=.025$) and asynchronous condition (critical $p=.025$) are reported below.

	AN ($n=30$)		HC ($n=30$)		Mann–Whitney U test			
	M	SD	*M*	SD	MWu	*Z*	*p*	α
Synchronous								
Ownership subscale	7.96	2.04	6.59	2.65	298.50	−2.24	.025	.93
Control subscale	4.64	2.25	3.73	1.71	[a]1.78	n/a	.080	.86
Asynchronous								
Ownership subscale	4.08	2.23	3.42	1.88	357.50	−1.37	.171	.86
Control subscale	3.82	2.02	3.12	1.81	343.50	−1.58	.115	.91

[a] Data for the control subscale under the synchronous condition was normally distributed in both AN and HC group. For this variable group differences were assessed with an independent samples *t*-test (df=58), the *t*-value is reported in the MWu column.

more affirmatively than HC. This conclusion is further supported by absence of significant differences between AN patients and HC on their ratings of the EQ under the asynchronous condition.

Ratings of pleasantness of tactile stimulation were not normally distributed (Shapiro–Wilk$_{AN}$(30)=.75, $p<.001$; Shapiro–Wilk$_{HC}$(30)=.90, $p=.007$). A non-parametric Mann–Whitney U test showed that patients and HC did not differ on ratings of tactile stimulation ($M_{AN}=8.70$, SD=1.42; $M_{HC}=8.40$, SD=1.28, Mann–Whitney U=370.00, $Z=-2.11$, $p=.222$).

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. Under the synchronous condition mean proprioceptive drift was 2.35 cm (SD=2.31) for AN patients, and 1.79 cm (SD=3.39) for HC. Under the asynchronous condition mean proprioceptive drift was 1.03 (SD=1.72) for AN patients and .27 cm (SD=2.03) for HC. There was no correlation between BMI and proprioceptive drift, therefore we did not control for BMI in analyses (see Supplementary Tables).

Part of the data violated the assumption of normality (Shapiro–Wilk test AN$_{sync_condition}$=.94, $p=.090$; AN$_{async_condition}$=.90, $p=.010$; HC$_{sync_condition}$=.64, $p<.001$; HC$_{async_condition}$=.82, $p<.001$), therefore non-parametric tests were performed. First, Wilcocox signed ranks tests showed that in both AN and HC group proprioceptive drift was larger under the synchronous vs asynchronous conditions ($Z_{AN}=-3.41$, $p=.001$; $Z_{HC}=-3.39$, $p=.001$), indicating that the illusion was successfully induced in both groups. Bonferroni corrected Mann–Whitney U tests (critical $p=.025$) showed no differences between AN and HC group in proprioceptive drift for the synchronous condition (Mann–Whitney $U=332.00$, $Z=-1.75$, $p=.081$, Cohen's $d=.19$ or the asynchronous condition (Mann–Whitney $U=302.00$, $Z=-2.19$, $p=.029$, Cohen's $d=.40$). Thus, in contrast to findings by Eshkevari et al. (2012) we did not observe larger proprioceptive drift in the AN group compared to the HC group.

3.3. Size estimation

3.3.1. Actual size and general performance on hand size estimation

Of the 18 variables of interest, two were not normally distributed: Actual wrist width for AN patients, Shapiro–Wilks (30)=.928, p=.044 (all other p's in the AN group >.086) and size estimation of the width of the rubber hand for HC, Shapiro–Wilk (30)=.906, p=.012 (all other p's in the HC group >.137). For analyses involving these two not normally distributed variables we reported the results of non-parametric tests.

First, Bonferroni corrected independent samples t-tests and a Mann–Whitney U test (critical p=.017) showed that AN patients and HC did not differ on actual hand width, $t(58)=-.97$, p=.334 (Levene's F=.81, p=.371); wrist width, Mann–Whitney U=416.50, $Z=-.50$, p=.620 and length of own hand, $t(58)=-1.34$, p=.186 (Levene's F=3.32, p=.074), see Table 4. Bonferroni corrected paired samples t-tests and a Wilcoxon signed ranks test (critical p=.017) showed that for AN patients actual hand size did not differ from rubber hand size. This was specifically found for hand width, $t(29)=1.85$, p=.074, wrist width Wilcoxon signed ranks test $Z=-1.66$, p=.098, and hand length, $t(29)=1.44$, p=.161. HC hand width, $t(29)=2.70$, p=.012, wrist width, $t(29)=5.10$, p=<.001, and length of own hand, $t(29)=4.61$, $p<.001$ were all larger than hand width, wrist width, and length of the rubber hand, see Table 4.

Second, Bonferroni corrected one sample t-tests and a Wilcoxon signed ranks test (critical p=.017) showed that before the RHI was induced AN patients overestimated own hand width, $t(29)=-3.26$, p=.003. AN patients correctly estimated own wrist width, Wilcoxon signed ranks test $Z=-.91$, p=.361, and own hand length, $t(29)=-1.28$, p=.210. HC correctly estimated own hand width, $t(29)=-.77$, p=.446, wrist width, $t(29)=-1.91$, p=.066, and hand length, $t(27)=.46$, p=.651, see Table 4.

Third, Bonferroni corrected one sample t-tests and a Wilcoxon signed ranks test (critical p=.017) showed that before induction of the RHI, AN patients correctly estimated hand width, $t(29)=1.40$, p=.174, and length of the rubber hand, $t(29)=-1.94$, p=.062, they overestimated wrist width of the rubber hand, $t(29)=-2.92$, p=.007. HC correctly estimated hand width, Wilcoxon singed ranks test $Z=-.75$, p=.453, wrist width, $t(29)=-1.84$, p=.075, and length, $t(29)=-2.14$, p=.041 of the rubber hand, see Table 4.

Taken together, in terms of width the rubber hand was equal to actual hand width of AN patients, but smaller than HC's hand width. AN patients and HC did not differ in actual hand size. AN patients overestimated the width of their own hand, but correctly estimated the width of the wrist and length of their own hand. HC correctly estimated all parts of their own hand. AN patients overestimated the width of the wrist of the rubber hand, but correctly estimated width and length of the rubber hand. HC correctly estimated all three measures of the rubber hand. For the absolute values of hand size and hand size estimation, see Table 4.

Table 4
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=30)				HC (n=30)			
	Rubber hand		Own hand		Rubber hand		Own hand	
	M	SD	*M*	SD	*M*	SD	*M*	SD
Actual dimensions								
Width	71.09	.00	72.18	3.25	71.09	.00	73.12	4.13
Wrist	49.10	.00	51.86	2.65	49.10	.00	51.39	2.46
Length	87.33	.00	89.23	7.22	87.33	.00	91.34	4.77
Size estimation								
Width	69.35	6.80	77.47	8.23	71.24	5.88	73.97	7.29
Wrist	52.81	6.95	56.99	7.61	50.70	4.75	53.30	5.17
Length	90.21	8.15	91.61	6.72	91.83	11.50	90.52	11.34

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 5). Note that positive values indicate an increase in size estimation after induction of the RHI, and negative values a decrease in size estimation. There was no correlation between BMI and differences in size estimation, see Supplementary Tables, therefore we did not control for BMI in

Table 5
Difference in size estimation in mm before and after induction of the RHI for the rubber hand and own hand, by group and condition. Results of Bonferroni corrected one sample t-tets and a Wilcoxon signed ranks test (critical p=.004) are reported below.

	AN (n=30)				HC (n=30)			
	M	SD	t (df=29)	p	*M*	SD	t (df=29)	p
Rubber hand								
Synchronous condition								
Width	2.54	5.90	2.36	.025	1.51	6.00	1.38	.179
Wrist	2.30	4.84	2.60	.015	1.93	4.40	2.41	.023
Length	.41	8.29	.28	.781	−1.12	8.50	−.72	.475
Asynchronous condition								
Width	1.64	6.76	1.33	.193	−.98	5.20	−1.03	.312
Wrist	1.91	5.94	1.76	.088	1.32	3.24	2.23	.034
Length	−.75	10.55	−.39	.698	−2.39	9.26	−1.42	.168
Own hand								
Synchronous condition								
Width	−7.62	6.76	−8.16	.000	−2.38	5.02	−2.60	.014
Wrist	−1.86	4.87	−2.09	.045	.37	3.66	[a] −.93	.926
Length	−2.15	5.77	−2.04	.050	−.12	5.77	−.11	.911
Asynchronous condition								
Width	−6.62	6.76	−5.37	.000	−2.35	4.45	−2.90	.007
Wrist	−1.34	4.69	−1.56	.129	−.40	3.48	−.62	.539
Length	−3.27	7.06	−2.55	.016	−1.66	7.21	−1.26	.218

[a] The difference score for own wrist width under the synchronous condition in the HC group was not normally distributed (Shapiro–Wilk(30)=.93, p=.049). We performed a Wilcoxon signed ranks test for this variable (we paired the difference score for own wrist width under the synchronous condition with a dummy variable that had the value zero). The Z-value is reported in the t-value column.

analyses. In the HC group the difference score for own wrist width under the synchronous condition was not normally distributed, Shapiro–Wilk(30)=.93, p=.049 (all other p's in the HC group $>$.063 and in the AN group $>$.297). For analyses involving this not normally distributed variable we reported the results of non-parametric tests, see Table 5.

First we compared the difference scores to zero in a Bonferroni corrected one sample t-test (critical p=.004) for each group (AN and HC) and each part of the hand (width, wrist, and 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 ($M=-7.62$ mm, SD=6.76, $t(29)=-8.16$, $p<.001$, and Cohen's $d=3.03$) and asynchronous condition (M=6.62, SD=6.75, $t(29)=-5.37$, $p<.001$, and Cohen's d=1.99) as smaller after induction of the RHI (see Table 5). These two difference scores did not significantly differ from each other, $t(29)=-.79$, p=.443.

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 hand. The results of the Bonferroni corrected (critical p=.025) paired samples t-test indicated no significant difference under both synchronous and asynchronous conditions, $t_{synchronous}(29)=1.40$, p=.173; $t_{asynchronous}(29)=.72$, and p=.478. Note that before induction of the RHI, AN patients' size estimation for own hand width *did* differ from actual hand width $t(29)=-3.26$, p=.003. 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, $t_{synchrounous}(29)=-.34$, p=.737; $t_{asynchrounous}(29)=-.42$, and p=.680.

Taken together these results show that after induction of the RHI under both synchronous and asynchronous conditions AN patients estimated own hand width more accurately compared to before induction of the RHI. When effect size is inspected it appears that the largest effect is present under the synchronous condition. Note that post-size estimation of hand width in the AN group did not significantly differ from the width of the rubber hand.

3.3.3. *Correlation between hand size estimation, RHI measures and clinical (pathology) 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 subscale and EQ Control subscale), perceptual RHI measures (i.e. proprioceptive drift), pleasantness ratings of tactile stimulation, hand size estimation and clinical measures.

As for the correlation between BMI and participants' own hand size estimation before induction of the RHI, no significant correlation between BMI and pre-hand width estimation (r=.34, p=.065), pre-wrist width estimation (r=.21, p=.266) and pre-hand length estimation (r=.02, p=.899) was found in the AN group. In the HC group no correlation between BMI and pre-hand width estimation ($r=-.03$, p=.893), pre-wrist width estimation (r=.01, p=.974) and pre-hand length estimation ($r=-.18$, p=.331) was found either. Similar results were found for the correlation between BMI and size estimation of the rubber hand before induction of the RHI. In the AN group, pre-size estimation of the width of the rubber hand (r=.05, p=.806), width of the wrist of the rubber hand ($r=-.05$, p=.787) and length of the rubber hand ($r=-.22$, p=.238) did not correlate with BMI. In the HC group, pre-size estimation of the width of the rubber hand ($r=.-.34$, p=.068), width of the wrist of the rubber hand ($r=-.33$, p=.076) and length of the rubber hand ($r=-.21$, p=.265) did not correlate with BMI.

Further, we did not find significant correlations between any of the variables, except for two which did not lend themselves for further interpretation (in the HC group the ownership subscale under the asynchronous condition correlated with the depression subscale of the DASS, $r=-.59$, p=.001, in the AN group the difference in pre and post size estimation of the width of rubber hand under the synchronous condition correlated with proprioceptive drift under the synchronous condition, r=.56, p=.001), see online Supplementary Tables.

4. Discussion

Recent studies indicate multimodal body representation disturbances in AN (e.g. Case, Wilson, & Ramachandran, 2012; Guardia, Cottencin, et al., 2012; 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. 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 as measured with the EQ in AN patients compared to healthy females, which partly replicates previous findings by Eshkevari et al. (2012). In their study Eshkevari et al. (2012) observed larger embodiment scores in the AN group compared to healthy females in the synchronous as well as asynchronous (control) condition. The effect we observed in the current study is more specific: AN patients only rated statements related to the experience of ownership over the rubber hand as higher than healthy females under the synchronous (experimental) condition. The two groups did not differ on ratings of the ownership subscale under the asynchronous condition, nor on the subscale consisting of control questions (i.e. "it felt as if my real hand was turning "rubbery" of "it felt as if I had more than one left hand") under both synchronous and asynchronous (control) conditions. This makes it unlikely that the current findings are the result of AN patients having a tendency to respond affirmatively when participating in research. Rather, AN patients show a specific strong subjective experience of ownership over the rubber hand after successful induction of the RHI. In other words, they experience the illusion more strongly compared to healthy females. It appears that AN patients show altered processing of multisensory information, resulting in increased proneness to accept a rubber hand as belonging to their own body on a self-report level.

Overall, in both AN group and healthy females proprioceptive drift was larger under the synchronous than asynchronous (control) condition. This finding confirmed the results of the Embodiment Questionnaire outlined above, in that the subjective ratings of ownership over the rubber hand under the synchronous condition were also higher than under the asynchronous condition (i.e. participants did not experience ownership over the rubber hand under the asynchronous condition). As such, the RHI has been successfully induced in both groups. In contrast to findings by Eshkevari et al. (2012) we did not observe larger proprioceptive drift in the AN group compared to healthy females under either synchronous or asynchronous condition. Inability to replicate the results found by Eshkevari et al. (2012) regarding proprioceptive drift may be due to a power issue. Eshkevari et al. (2012) 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 be noted however 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, Di Luca, & Ernst, 2011). For example Rohde et al. (2011) suggest that the experience of ownership relies on visuotactile integration, whereas proprioceptive drift involves a distinct mechanism, visuoproprioceptive integration. This proposed dissociation between ownership and drift could explain why under the synchronous condition AN patients have a stronger RHI on a subjective level compared to healthy females, but not a perceptual level.

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., 2008). 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 & 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 & Haggard, 2007; Tsakiris & 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, Tajadura-Jimenez, and Costantini (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 & 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).

As for neural correlates of the subjective experience of the RHI, various studies have implicated the insular cortex in subjective awareness and affective processing of bodily signals (e.g. Craig, 2002, 2009; Dijkerman & de Haan, 2007). The right posterior insula specifically has been ascribed an important role in for example ego-centric representations of the body (Fink et al., 2003), experiencing body-ownership (Baier & Karnath, 2008), self-recognition (Devue et al., 2007), and agency (Farrer et al., 2003). Not surprisingly, this structure has also been related to experiencing ownership over a rubber hand in the RHI (e.g. Tsakiris, 2010; Tsakiris, Hesse, Boy, Haggard, & Fink, 2007; Tsakiris, Schutz-Bosbach, & Gallagher, 2007). Lesion studies have shown that the insula is critical in somatoparaphrenia (i.e. denial of ownership over a limb, for a review see (Vallar & Ronchi, 2009), while a sparse number of studies show increased activation in the (right posterior) insula in AN patients (see e.g. Nunn et al., 2011; Strigo et al., 2013). It could thus be that increased activation of the right posterior insula in AN results in a heightened ease with which the representation of the body can be adjusted, for example to include a rubber hand. Note that we asked participants to rate pleasantness of tactile stimulation during induction of the RHI. Both AN patients and HC rated tactile stimulation as highly pleasant, and did not differ on this measure. One could argue that insular (dys)functioning is relevant in assigning emotional valance to sensory input such as touch. However we believe that subjective pleasantness ratings of tactile stimulation are not an ideal measure of interoceptive awareness. Here we mainly included this measure to ensure that tactile stimulation in itself was not experienced more negatively by AN patients, which could have biased the RHI. Future studies can investigate the relation between RHI and interoceptive awareness more directly by including for example a task in which participants are asked to count their own heartbeat.

4.2. Size estimation and the rubber hand illusion

First, before induction of the RHI, both AN patients and healthy females correctly estimated the size of the rubber hand, except for the size estimate of wrist width, which was overestimated by AN patients. Healthy females correctly estimated the size of their own hand, while AN patients overestimated own hand width, but not own wrist width and hand length. As also touched upon in the introduction, there are numerous studies that show multimodal overestimation of body size in AN (see e.g. Cash & Deagle, 1997; Guardia et al., 2010; Keizer et al., 2011; Nico et al., 2010; Skrzypek et al., 2001), while some others are not in favor of this conclusion (see eg Cornelissen et al., 2013; Farrell et al., 2005). Our results of hand size estimation from the current study fall in between, AN patients overestimate hand width, but not wrist width and hand length.

It has been suggested that overestimation of body size is related to an underweight body state (Cornelissen et al., 2013). In the current study this seems unlikely, as we included both underweight AN patients and EDNOS patients who attained a healthy weight. These two groups did not differ on any of the variables of interest. In addition, no relevant correlations with BMI were found. For example, BMI did not correlate with baseline hand size estimation (i.e. size estimation before induction of the RHI) in either the AN or the HC group. More importantly, it should be noted that although altered perception of the body is thought be disturbed in AN at a general level, it has been found that it is more severe for body parts that are emotionally salient for AN patients, such as the abdomen (see e.g. Keizer et al., 2012). Here we included the hand, which may be regarded as a relatively emotionally "neutral" body part for AN patients, as such, disturbed size perception might be less pronounced.

As for hand size estimation after induction of the RHI, AN patients' size estimations of own hand width was on average 7.62 mm (synchronous condition) and 6.62 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, but 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 (2009) findings. 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. For AN patients, hand size was equal to the rubber hand, and they overestimated the width of their own hand prior to induction of the RHI. After induction of the RHI, they indeed showed a decrease in size estimation of the width of their own hand. However, following this hypothesis, our results should also have shown a decrease in size estimation in healthy females, as their hand size, which they correctly estimated before induction of the RHI, was larger than that of the rubber hand. This was not the case. Perhaps the difference in hand size between the own hand of the healthy females and the rubber hand was too small (~2 mm) to induce a change in hand size estimation.

What is particularly interesting is that our results showed changes in size estimations of own hand width in the AN group after both synchronous and asynchronous (control) conditions 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 under 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, thus they only showed a decrease in size estimation for that part of the hand that they overestimated prior to induction of the RHI.

We offer two possible explanations for the found results. First, during the induction of the RHI under both synchronous and asynchronous (control) conditions participants were instructed to focus their attention on the rubber hand lying in front of them. 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 (memory of the) size of the rubber hand lying in front of them. This would indicate that simply visually exposing AN patients to a rubber hand placed in an anatomically congruent position would be sufficient for this effect to occur. Related to this, under synchronous as well as asynchronous (control) conditions healthy females showed a trend towards a decrease in size estimation of hand width, i.e. their size estimate became more in line with the dimensions of the rubber hand, similar to the effect found in AN patients, only not significant. It could be argued that the effect found in AN patients is an exaggerated normal effect. However, the trend in decreased size estimation in the healthy control group is specific for the width of their hand. Would a normal effect consist of making size estimates of hand width based on the most recent visual information of a hand (in this case, the rubber hand), it would be expected that healthy females would also show a (trend towards a) decrease in size estimation of the width of their wrist and length of their hand, as these dimensions of their hand were larger than those of the rubber hand as well. We therefore render it unlikely that the change in size estimation of own hand width in the AN group is an inflated normal effect.

This however does not imply that decreased size estimation in the AN group cannot be the result of AN patients making their size estimates based on (the memory of) recent visual input of a hand. If this indeed is the case, one might even suggest that AN patients do not have a perceptual deficit regarding body size, but a tendency to base their body size estimations on the memory of body size (i.e. only the cognitive construct of body size is distorted, not perception in itself). However, a recent study showed that AN patients who were asked to estimate their own body size fail to do this accurately when instructed to do so from memory *and* when instructed to do this based on what they see in a mirror placed in front of them (Overas, Kapstad, Brunborg, Landro, & Lask, 2014). This makes it unlikely that AN patients do not have a perceptual deficit, but overestimate body size because they estimate body size based on the memory of the most recent visual input.

A second explanation for the decrease in size estimation of the width of the hand in the AN group might be related to changes in available sources of sensory information on which a size estimation can be based. During induction of the RHI, under both synchronous and asynchronous (control) condition, participants kept their hand very still, and moved it only after they made size estimations of their own hand and the rubber hand. By keeping the hand still, proprioceptive input was reduced, while stroking of the hand provided "new" tactile input. Reduction of proprioceptive input and providing tactile input could have resulted in an update of their body representation, which was more influenced by tactile input. Interestingly, chronic pain patients have also been found to have a distorted (bigger) experience of the size of their affected body part (Moseley, 2005). In this group it was found that providing a training involving tactile stimulation had a beneficial effect on the amount of reported pain and restored previously diminished tactile acuity (Lotze & Moseley, 2007). Although the experienced size of the body part was not directly assessed, these findings do suggest that the representation of the body (or part of it) in the brain can be altered via tactile input.

Future studies can explore the validity of these two possible explanations for the decreased size estimation observed here in AN patients by for example testing whether AN patients still show this effect when tactile input is removed, i.e. merely viewing the rubber hand and making a size estimation, and vice versa, by removing the rubber hand but still providing tactile input on the actual hand.

4.3. Conclusion and clinical implications

The present study shows two main findings. First, AN patients had a stronger experience of ownership over the rubber hand in the RHI than healthy females under the synchronous but not the 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) under both synchronous and asynchronous conditions. 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 in the sense that the hand is a relatively neutral body part and less emotionally salient for AN patients than for example the abdomen or hips. Nevertheless, AN patients in the current study 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 behavioral 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 under both synchronous and asynchronous (control) conditions of the RHI. In the latter, no multisensory integration took place. It might be related to another aspect of the RHI paradigm. Under both synchronous and asynchronous conditions 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 providing multisensory input when attempting to change the experience of body size. For example using a tactile training similar to the one used by Lotze and Moseley (2007) in chronic pain patients. During this training patients were asked to identify the location of tactile stimuli on their affected body part, this combination of direct attentional focus on the body and providing tactile input proved to be beneficial (Lotze & Moseley, 2007).

We identified differences in both experience of ownership over the rubber hand, and size estimation of the hand between AN patients and HC. This 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; Preston & Ehrsson, 2014). This would give insight into whether our findings extend to different parts of the body, and enhance clinical applicability of the results.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.neuropsychologia.2014.07.003.

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