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INCREASED PLASTICITY OF THE BODILY SELF IN EATING DISORDERS

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ABSTRACT

Background: The rubber hand illusion (RHI) has been widely used to investigate the bodily self in healthy individuals. The aim of the present study was to extend the use of the RHI to examine the bodily self in eating disorders. **Methods:** The RHI and self-report measures of eating disorder psychopathology (EDI-3 subscales of Drive for Thinness, Bulimia, Body Dissatisfaction, Interoceptive Deficits, and Emotional Dysregulation; DASS-21; and the Self-Objectification Questionnaire) were administered to 78 individuals with an eating disorder and 61 healthy controls. **Results:** Individuals with an eating disorder experienced the RHI significantly more strongly than healthy controls on both perceptual (i.e., proprioceptive drift) and subjective (self-report questionnaire) measures. Furthermore, both the subjective experience of the RHI and associated proprioceptive biases were correlated with eating disorder psychopathology. Approximately 20% of the variance for embodiment of the fake hand was accounted for by eating disorder psychopathology, with interoceptive deficits and self-objectification significant predictors of embodiment. **Conclusions:** These results indicate that the bodily self is more plastic in people with an eating disorder. These findings may shed light on both aetiological and maintenance factors involved in eating disorders, particularly visual processing of the body, interoceptive deficits, and self-objectification.

INTRODUCTION

The rubber hand illusion (RHI) paradigm, developed by Botvinick and Cohen [1], has been widely used for investigating embodiment, including sensory-driven body ownership, body awareness, and perceptual body image [2,3,4,5,6]. Participants view a fake rubber hand placed in front of them, slightly to one side but in a similar position to their own hand, which is hidden from view. Both the rubber hand and the participant's own hand are then stroked, either synchronously or asynchronously. When the fake hand is stroked in synchrony with one's own hand, one feels the touch on the fake hand, as if the fake hand belonged to oneself. A striking and easily quantifiable aspect of the illusion is that the perceived position of one's own hand shifts towards the fake hand. However, this illusion is reduced if the stroking of the fake and real hand is asynchronous.

The RHI is often interpreted as a three-way interaction between the sensory modalities of touch, vision, and proprioception, whereby the synchrony of visual and tactile input leads to an overriding of the proprioceptive input [7,8]. There are two essential components which underlie the emergence of the illusion and each represents a distinct aspect of body representation. The first component is that the participant sees a hand that is in a posture and location consistent with their real hand. This represents visual capture, where the visible fake hand can override proprioception of the real hand and be experienced as one's own, and this component of body perception is present in both the synchronous and asynchronous conditions of the RHI. Indeed, some studies have found clear effects of the RHI in the absence of any touch at all (e.g., Pavani et al., 2000, Psychol Sci; Farne et al., 2000, Brain). The second component underlying embodiment of the rubber hand is that there is a temporal and spatial correlation of seen and felt touch. This component of body perception represents multisensory integration and is present only in the synchronous condition.

Body image is a major focus of psychopathology in eating disorders, but it has proved difficult to measure objectively. Subjective factors, which are a persistent limitation in examining body image in people with eating disorders can strongly bias basic measures of bodily awareness, making it difficult to separate perceptual, emotional, and cognitive contributions. However, the hand is a body-part that is not considered to be salient or important in weight and shape evaluations for most individuals, including those with an eating disorder [9]. As such, the RHI may be less confounded by emotional and cognitive factors than body image measures focused on weight and shape, which are typically used to assess body image in eating disoders. The only previous RHI study relevant to eating disorders is that by Mussap and Salton [9], who tested a sample of undergraduates. They found that the strength of the self-reported experience of the illusion was significantly associated with bingeing and purging behaviours, drive for muscularity, exercise levels, and chemical supplement use. Furthermore, Mussap and Salton [9] found that internalisation of sociocultural standards mediated the relationship between the RHI and levels of both bulimic symptoms and body change behaviours (e.g., use of dietary supplements and exercise). These preliminary findings indicate that research examining the RHI in individuals with an eating disorder and its relationship with eating disorder psychopathology could be of benefit in gaining an understanding of the bodily self in people with an eating disorder.

The aim of the present study was to investigate the experience of the bodily self in individuals with an eating disorder by using the RHI paradigm. As described above, the RHI reflects a dominance of visual information about the fake hand over proprioceptive information from one's own hand. To the extent that eating disorders involve a strong attention to the visual appearance of the body [10,11], and a disturbance in interoception, which is the internal representation of how one's own body really is [12,13], we predicted that visual dominance over proprioception would be particularly strong in an eating disorder group, relative to a healthy control group. Therefore, it was hypothesised that people with an eating disorder will experience a stronger illusion with the RHI than healthy controls. It was further hypothesised that individual differences in the experience of the RHI will be related to eating disorder psychopathology.

METHOD and MATERIALS

Participants

Participants were eligible to take part if they were female, between 18 and 55 years of age, right-handed, had no history of head/brain injury, no history of drug/alcohol abuse, no learning disability, no medical illness with symptom overlap with eating disorders, and spoke English proficiently. In addition to these inclusion/exclusion criteria for all participants, participants in the healthy control (HC) group were required to have a body mass index (BMI = kg/m^2) between 18.5 and 25, to not currently be on a diet to lose weight or have had a history of being underweight (BMI < 17.5), to not have any history of an eating disorder or disordered eating behaviour, and to not have a current or prior history of psychiatric illness (as defined in the DSM-IV-TR) [14]. Individuals in the eating disorder (ED) group were required to meet, in addition to the criteria for all participants, DSM-IV-TR [14] diagnostic criteria for an eating disorder.

Participants were recruited from students and staff at a UK tertiary institution, an eating disorder research volunteer database at this institution, and posters in public and medical settings. Ethical approval was obtained from the Psychiatry, Nursing & Midwifery Research Ethics Sub-Committee (PNM/09/10-19), King's College London. All participants provided informed consent in order to take part and were offered financial reimbursement for their time and travel.

Measures

<u>Structural Clinical Interview for Diagnosis, Research Version. (SCID-I) [15]</u>

A tailored version of the SCID-I (i.e., only the overview, screening, and eating disorders modules), which is a standardised interview for diagnostic assessment of DSM-IV disorders, was administered to assess participants to ensure they met the inclusion criteria and to allocate them to the appropriate group.

Eating Disorder Inventory – 3 (EDI-3) [16]

The EDI-3 is a 91-item self-report questionnaire of psychological traits clinically relevant in individuals with an eating disorder. Participants respond on a 6-point likert scale ("Always" through to "Never"). This study reports only on the EDI-3 subscales of Drive for Thinness, Bulimia, Body Dissatisfaction, Interoceptive Deficits and Emotional Dysregulation. The sum of the Drive for Thinness, Bulimia, and Body Dissatisfaction subscales comprises the Eating Disorder Risk scale. Cronbach's α ranged from .82-.95 for the EDI-3 subscales in this sample, which is similar with those published by Garner [16] of .67-.95.

Self-Objectification Questionnaire (SOQ) [17]

The SOQ is a 10-item self-report assessment of self-objectification. It assesses the extent to which individuals view their bodies in observable, appearance-based (objectified) terms (e.g., physical attractiveness and body measurements) versus non-observable, competence-based (non-objectified) terms (e.g., healthiness and physical energy level). Participants rank a list of 10 body attributes in order of how important each is to their physical self-concept.

Depression Anxiety Stress Scales – 21 Item Version (DASS-21) [18]

The DASS-21 is a 21-item, three-scale, self-report measure of mood disturbance. Namely, depression, anxiety, and stress. Each scale consists of 7 items and participants respond on a 3-point likert scale ("0 = did not apply to me over the past week", through to "2 = applied to me very much or most of the time over the past week"). The DASS-21 also provides a total score, which is the sum of all items. Cronbach's α was .95 for the Depression scale, .89 for the Anxiety scale and .90 for the Stress scale in this sample, which is similar to those reported by Lovibond and Lovibond [18] of .91 for the Depression scale, .84 for the Anxiety scale and .90 for the Stress scale.

Edinburgh Handedness Inventory (EHI) [19]

The EHI is a 10-item self-report measure that assesses handedness, defined as the dominance of a person's right or left hand in every day activities. It was used to ensure participants were right handed. Cronbach's α was .53 in this sample.

Outcome measures of the Rubber Hand Illusion (RHI)

The RHI paradigm performed in this research was based on the original version [1] and is outlined in detail in the Procedure section. The two most widely used outcome measures of the RHI were used, namely, (i) proprioceptive drift and (ii) self-report questionnaire (providing the embodiment score). Proprioceptive drift is a quantitative perceptual measure of the illusion. Participants are asked to indicate the position of their own unseen hand using a ruler placed on the worksurface prior to and following visuotactile stimulation. Bias in these proprioceptive judgements towards the fake hand due to visuotactile stimulation is taken as a measure of the visual dominance of the fake hand over proprioception of one's own hand.

The self-report questionnaire provides a subjective cognitive measure of the illusion, and is designed to summarise the experience of embodiment over the rubber hand. The questionnaire was developed from the 10 items found to comprise an embodiment factor in Longo and colleagues' [4] study. Cronbach's α was .94 in this sample for the questionnaire. Participants were required to respond to the 10 items on a 7-point Likert scale, ranging from -3 = "strongly disagree" through to +3 = "strongly agree" and an embodiment score was calculated from the mean of the 10 item scores. These are outlined in further detail below.

Height and weight

Height and weight were measured by the experimenter. Self-report values were requested when a participant declined weight and height measures to be taken. However, three participants with anorexia nervosa further declined self-report estimates of weight, such that BMI could not be calculated for these participants.

Procedure

Each participant was tested in a single session. The SCID-I was administered first, followed by the questionnaires, RHI task, and finally height and weight were measured. For the RHI task, the participant was seated at a table opposite the experimenter, with their left arm placed through an entrance hole and resting in a specially constructed box (100cm x 35cm x 18cm, illustrated in Figure 1). A life-sized model of a left hand and forearm was placed in the box, directly in front of the participant at the body midline. The participant could see this fake hand through a hole on the top of the box. The box had a hinged cover to expose the fake hand and hide the experimenter from view (and vice versa). Participants wore a cloth smock, which was attached to the front of the box and hid the participant's real arm from view. The bottom of the inside of the box was lined with black felt and there was a small felt disk placed for the participant to mark where they should place the tip of their left index finger. The distance between the participant's index finger and the index finger of the fake hand was 20cm. The back of the box was completely removed to allow the experimenter to access the participant's hand and the fake hand.

Two visuotactile induction conditions, asynchronous and synchronous, were performed. The participant was first seated as described above, and the box cover closed. Prior to each trial, a finger location judgement was obtained by placing a ruler across the top of the box and asking the participant to indicate where they felt the tip of their left index finger was located. The placement of this ruler varied from trial to trial in order to prevent participants repeating responses in subsequent trials. After this, the cover of the box was raised and the participant was instructed to focus their attention on the rubber hand while two paintbrushes (Winsor & Newton, London) stroked the fake hand and the participant's real hidden hand (at approximately 1 stroke per second). In the synchronous condition, the timing of the brush strokes was synchronised, whereas in the asynchronous condition the timing of the brush strokes was out of time such that there was an offset between the stroking of the rubber hand and the real hand (i.e., out of phase by 180 degrees). Following this, the box cover was lowered and a post-induction finger location judgement was obtained in the same manner as prior to the induction. The order of the conditions (synchronous and asynchronous) was randomised. The RHI questionnaire was administered verbally after each trial, with the scale presented on a card placed in front of the participant, on the box.

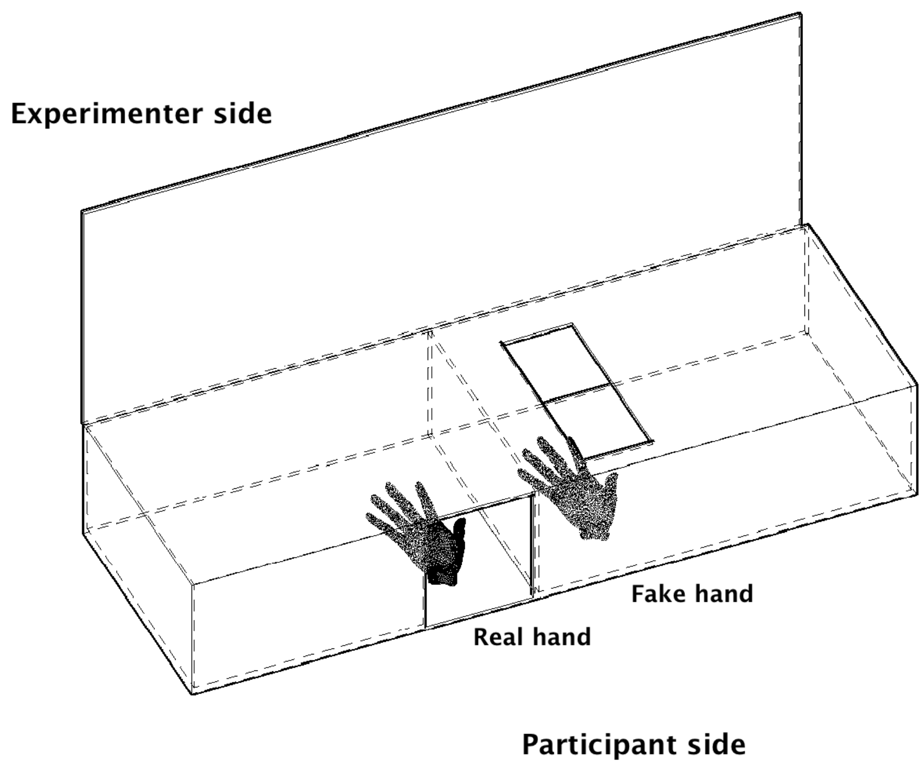

Figure 1: *Rubber hand illusion apparatus. In this view, the box lid is lifted up, so the participant can view the fake hand and the experimenter is out of sight.*

Analyses

Finger location judgement was calculated as the difference between the position reported by the participant and the actual position of the participant's finger. A positive value indicates a judgement to the right of a participant's actual finger location (i.e., towards the midline and towards the fake hand) and a negative value indicates a judgement to the left of the actual finger location (i.e., away from the midline and fake hand). Proprioceptive drift was was calculated from subtracting the pre-induction finger location judgement from the post-induction finger location judgement.

The statistical software used was SPSS (v 17). The significance level for all analyses was set at $p < .05$ and results reported are two-tailed. Analyses performed tested for differences between the ED and the HC group, with subsequent analyses testing for differences between the eating disorder diagnostic subgroups and the HC. ANOVAs and ANCOVAs were used to examine the effect of visuotactile stimulation between groups. Bivariate correlations were performed to investigate the relationship between the clinical measures and the RHI outcome measures. A multiple linear regression analysis was carried out on the entire sample to explore the predictive factors of clinical symptomatology on the experience of the illusion (i.e., embodiment).

RESULTS

Participants

A total of 160 individuals participated in this study: 80 healthy controls (HC), and 80 individuals with an eating disorder (ED). Despite having reported to meet research inclusion/exclusion criteria during the recruitment process, 21 individuals were excluded: 19 HC individuals were primarily excluded for having a BMI > 25 or meeting the diagnostic crietria for a current/previous history of mood disorder and two ED participants were excluded as they did not meet diagnostic criteria for an eating disorder. Thus, the final sample consisted of 61 HC and 78 ED. Of those with an ED, 36 had anorexia nervosa (AN) (24 restrictive subtype and 12 binge/purge subtype); 22 individuals had bulimia nervosa (BN); and 20 individuals had an eating disorder not otherwise specified (EDNOS).

The demographic and clinical details of these participants are reported in Table 1. There was no significant difference between AN, BN or EDNOS from HC on age or handedness. Differences for all other variables were found between HC and each ED group in the expected directions. That is, the AN group had a significantly lower BMI than HC, and each ED group had significantly higher scores than HC on all the mood and eating-disorder related measures.

Table 1: Participant demographics and clinical details and comparisons with HC

	HC (n=61)	**EDNOS (n=20)**	**AN (n=36)**	**BN (n=22)**
Age	24.0 (7)	27.5 (16)	23.0 (18)	22.5 (10)
W-test		W = 2332.5, Z = -1.9, p = .064	W = 2986.0, Z = -.02, p = .982	W = 844.5, Z = -.8, p=.411
BMI	21.5 (2.80)	19.7 (5.54)	16.1 (2.71)	20.9 (4.28)
W-test		W = 593.0, Z = -2.0, p = .046	W = 595.0, Z = -8.1, p < .001	W = 832.0, Z = -.9, p = .35
Duration of illness (years)	0	11.5 (12)	6.0 (11)	7.0 (4)
W-test		W = 1891.0, Z = -8.8, p < .001	W = 1891.0, Z = -9.4, p < .001	W = 832.0, Z = -8.9, p < .001
Total DASS score	12.0 (11)	46.0 (36)	55.0 (51)	62.0 (42)
W-test		W = 1973.5, Z = -5.8, p < .001	W = 1998.0, Z = -7.4, p < .001	W = 1916.0, Z = -6.7, p < .001
DASS-Depression	2.0 (4)	17.0 (22)	22.0 (27)	26.0 (21)
W-test		W = 2027.5, Z = -5.3, p < .001	W = 2060.0, Z = -7.0, p < .001	W = 1933.0, Z = -6.6, p < .001
DASS-Anxiety	2.0 (2)	8.0 (12)	11.0 (14)	13.0 (12)
W-test		W = 2112.0, Z = -4.4, p < .001	W = 2181.5, Z = -6.2, p < .001	W = 2001.5, Z = -6.0, p < .001
DASS-Stress	6.0 (6)	20.0 (8)	22.0 (19)	25.0 (16)
W-test		W = 1963.5, Z = -5.9, p < .001	W = 2146.5, Z = -6.3, p < .001	W = 2040.0, Z = -5.4, p < .001

EDI- Drive for thinness	2.0 (4)	17.5 (10)	21.0 (7)	23.5 (8)
W-test		W = 1892.0, Z = -6.7, p < .001	W = 1902.0, Z = -8.2, p <.001	W = 1891.0, Z =-7.0, p <.001
EDI- Bulimia	1.0 (2)	4.5 (11)	6.0 (13)	23.5 (9)
W-test		W = 2115.0, Z =-4.3, p < .001	W = 2342.5, Z = -4.9, p < .001	W = 1891.0, Z = -7.0, p < .001
EDI- Body dissatisfaction	10.0 (12)	28.5 (11)	28.0 (11)	36.0 (8)
W-test		W = 1903.0, Z = -46.6, p < .001	W = 2008.5, Z = -7.3, p < .001	W = 1905.5, Z = -6.8, p < .001
EDI- Interoceptive deficits	1.0 (2)	14.5 (13)	17.5 (11)	20.0 (12)
W-test		W = 1967.0, Z = -6.0, p < .001	W = 1937.5, Z = -8.0, p < .001	W = 1919.5, Z = -6.8, p < .001
EDI- Emotional Dysregulation	1.0 (3)	9.0 (7)	8.0 (6)	10.0 (9)
W-test		W = 2031.5, Z = -5.3, p < .001	W = 2068.0, Z = -7.0, p < .001	W = 1925.5, Z = -6.7, p < .001
Self-objectification	-3.0 (21)	9.0 (26)	3.0 (18)	13.0 (15)
W-test		W = 2244.5, Z = -2.6, p = .010	W = 2602.0, Z = -2.7, p = .006	W = 2118.5, Z = -4.6, p < .001
Laterality quotient	87.5 (22.9)	90.0 (34.2)	88.9 (27.5)	88.1 (32.0)
W-test		W = 2497.0, Z = -.1, p = .964	W = 1751.0, Z = -.1, p = .921	W = 851.0, Z = -.8, p = .441

HC = healthy control group; EDNOS = eating disorder not otherwise specified group; AN = anorexia nervosa group; BN = bulimia nervosa group. Due to non-normal distributions, statistics reported are medians followed by the interquartile range in brackets and comparison tests reported beneath are Wilcoxon's rank-sum test (W-test) comparing with HC (for which bonferroni correction applied for significance value: .05/3=.0167)

Results on the rubber hand illusion task

Baseline finger location judgement: Baseline finger location judgements are displayed in Figure 2 below. The HC group reported a mean finger judgement of 1.8cm (SD = 2.3), whereas the ED group reported a judgement bias of 2.5cm (SD = 3.5). One-sample *t*-tests revealed that the bias towards the right (body midline) was significant for both HC *t*(60) = 5.98, $p < .001$ and ED *t*(76) = 6.25, $p < .001$ groups, but that this difference was not significant between the ED and HC groups in an unequal variance sample *t*-test *t*(131.8) = -1.48, $p = .142$.

Proprioceptive drift: Proprioceptive drift (see Figure 2) was analysed in a 2x2 mixed effects ANOVA, with the within-subjects factor of visuotactile stimulation (i.e., synchronous or asynchronous), and the between-subjects factor diagnostic group. The effect of type of visuotactile stimulation on proprioceptive drift was significant $F(1, 134) = 25.5$, $p < .001$, with significantly greater proprioceptive drift in the synchronous versus the asynchonous condition. In addition, there was a significant main effect for diagnostic group $F(1, 134) = 5.7$, $p = .018$, with significantly greater proprioceptive drift in the ED compared to the HC group. However, the interaction between type of visuotactile stimulation and diagnostic group was not significant $F(1,134) = .9$, $p = .339$. Controlling for mood (i.e., depression and anxiety) using ANCOVA did not change these findings.

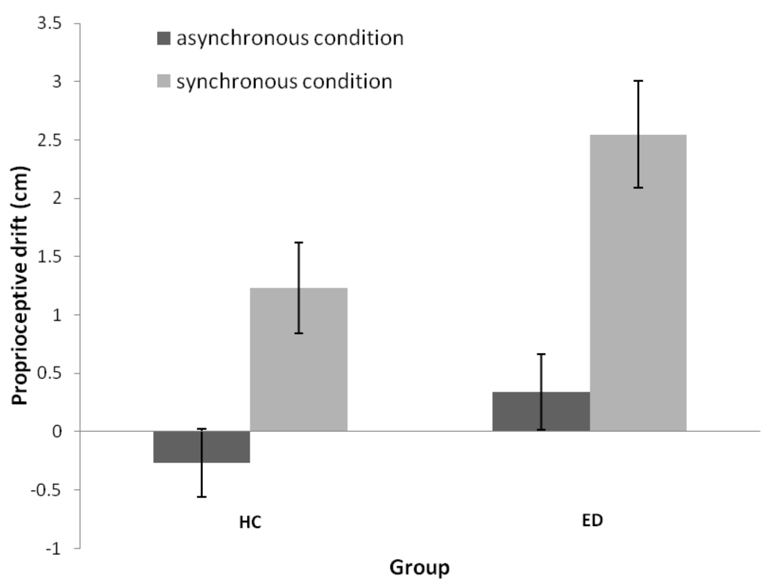

Figure 2: Mean and standard error of proprioceptive drift in each group for each RHI condition. Error bars

represent ±1 standard error of the mean.

Embodiment: The embodiment score (see Figure 3), was also analysed in a 2x2 mixed effects ANOVA (within-subjects factor was visuotactile stimulation and between-subjects factor was diagnostic group). The main effect for type of visuotactile stimulation on embodiment was significant $F(1, 135) = 131.9$, $p < .001$, with significantly greater embodiment self-reported in the synchronous versus the asynchronous condition. The main effect for diagnostic group was also significant $F(1, 135)=11.6$, $p = .001$, such that the ED group reported experiencing embodiment significantly more strongly than the HC group. However, the interaction between type of visuotactile stimulation and diagnostic group was not significant $F(1,135) = .01$, $p = .960$. Controlling for mood using ANCOVA did not change these findings.

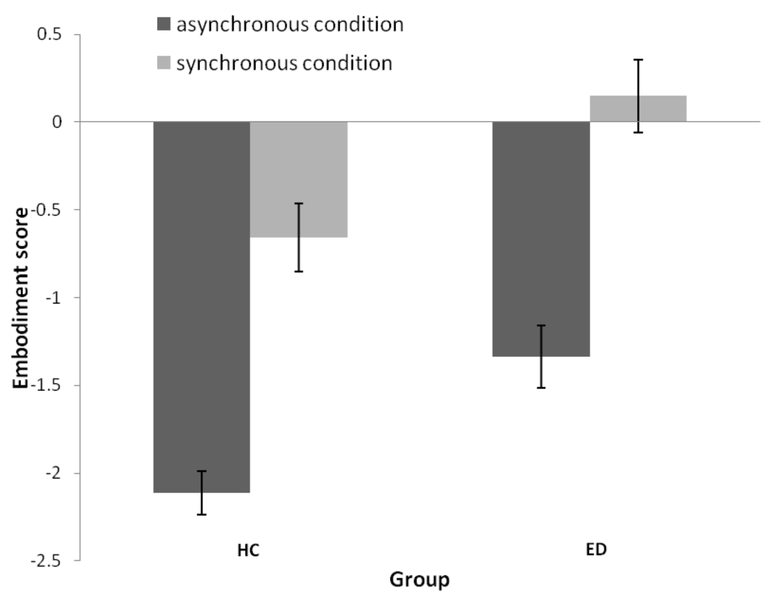

Figure 3: Mean and standard error of embodiment score in each group for each RHI condition. Error bars represent ±1 standard error of the mean.

Correlations between the RHI and eating disorder psychopathology measures

Due to the non-normal distributions for the questionnaire measures, Spearman's correlation coefficients were performed between the synchronous RHI measures and these measures. This was done using the whole sample and is presented in Table 2. Proprioceptive drift was positively associated with the embodiment score, *rho* = .40, $p < .001$. Both proprioceptive drift and embodiment were significantly correlated with each of the eating disorder psychopathology variables examined in the expected directions (i.e., Drive for Thinness, Body Dissatisfaction, Interoceptive Deficits, Emotional Dysregulation, Depression, Anxiety and Self-Objectification Questionnaire scores) except for Bulimia.

Table 2: Correlations (Spearman's rho) between synchronous RHI measures and clinical measures.

	BMI	Proprioceptive drift	Embodiment score	Drive for thinness	Bulimia	Body dissatisfaction	Interoceptive deficits	Emotional dysregulation	Self-objectification	Depression	Anxiety
Age	.08	.09	-.16	.03	.06	.04	-.11	-.05	-.23**	.04	-.11
BMI		-.19*	-.19*	-.40**	-.06	-.24**	-.43**	-.29**	-.17	-.36**	-.29**
Proprioceptive drift			.39**	.22*	.13	.23**	.22**	.22**	.19*	.17*	.26**
Embodiment score				.32**	.14	.33**	.33**	.30**	.44**	.26**	.26**
Drive for thinness					.68**	.83**	.76**	.71**	.47**	.73**	.63**
Bulimia						.65**	.58**	.62**	.37**	.62**	.51**
Body dissatisfaction							.74**	.73**	.48**	.76**	.70**
Interoceptive deficits								.79**	.34**	.79**	.71**
Emotional dysregulation									.41**	.79**	.66**
Self-objectification										.45**	.41**
Depression											.65**

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Regression analysis in predicting the RHI

A multiple linear regression analysis (entry method, presented in Table 3) was carried out on the entire sample to explore the predictive factors of eating disorder symptomatology and mood on the embodiment score from the synchronous condition. The Eating Disorder Risk Scale (sum of Drive for Thinness, Bulimia, and Body Dissatisfaction scales), BMI, duration of illness, Interoceptive Deficits scale, Self-Objectification Questionnaire and the DASS-21 (total score, sum of Depression, Anxiety and Stress scales) were regressed onto the embodiment score. The model was found to be significant $F(6, 110) = 4.9$, $p < .001$, predicting 20.6% of the variance (R^2=.206, adjusted R^2=.168). Interoceptive deficits and self-objectification were predictors that made a significant contribution to the model.

Table 3: An examination of the predictors of the RHI synchronous embodiment score

	Unstandardized Coefficients		Standardized Coefficients		
	B	**Std. Error**	**Beta**	**t**	**Sig.**
(Constant)	-.49	.85		-.57	.57
BMI	.00	.04	-.01	-.05	.96
Duration of illness	-.01	.02	-.03	-.26	.80
Eating disorder risk	-.01	.01	-.08	-.49	.62
Interoceptive deficits	.07	.03	.37	2.28	.02
Self-objectification	.05	.01	.36	3.77	.00
Mood	-.01	.01	-.13	-.85	.39

Dependent Variable: Synchronous embodiment score

Eating Disorder Risk = Sum of Drive for Thinness, Bulimia and Body Dissatisfaction scales

Mood = DASS total score, sum of Depression, Anxiety and Stress scale

Eating disorder subgroup analyses

Preliminary analyses were undertaken to explore possible differences between the AN and HC groups and between the BN and HC groups. The EDNOS group was not examined due to the heterogeneity of this group.

Baseline finger location judgement: It was found that the AN group was significantly more biased than the HC group: $t(51.9) = -2.2$, $p = .035$, while the BN group was not significantly different from the HC group: $t(25.59) = -.2$, $p = .835$.

Proprioceptive drift: Proprioceptive drift was analysed in a 2x2 mixed effects ANOVA (within-subjects factor of visuotactile stimulation condition, and the between-subjects factor diagnostic group). Comparing the AN and HC groups, the effect of type of visuotactile stimulation on proprioceptive drift was significant $F(1, 92) = 16.6$, $p < .001$, with significantly greater proprioceptive drift in the synchronous versus the asynchonous condition. There was a significant main effect for diagnostic group $F(1, 92) = 5.4$, $p = .022$, with significantly greater proprioceptive drift in the AN versus the HC group. However, the interaction between type of visuotactile stimulation and diagnostic group was not significant $F(1,92) = .4$, $p = .524$. Controlling for mood (i.e., depression and anxiety) using ANCOVA did not change these findings.

Comparing the BN and HC groups, the effect of type of visuotactile stimulation on proprioceptive drift was significant $F(1, 80) = 19.7$, $p < .001$, again with significantly greater proprioceptive drift in the synchronous versus the asynchronous condition. However, the main effect for diagnostic group was not significant $F(1, 80) = 2.5$, $p = .116$ and the interaction between type of visuotactile stimulation and diagnostic group was also not significant $F(1,80) = 2.4$, $p = .128$. Controlling for mood (i.e., depression and anxiety) using ANCOVA revealed a non-significant main effect of type of visuotactile stimulation $F(1, 78) =$

1.8, p = .190, a non-significant effect of group $F(1, 78) = 1.2$, p = .275, and a non-significant interaction effect $F(1, 78) = .05$, p = .832.

Embodiment: The embodiment score was also analysed in a 2x2 mixed effects ANOVA (within-subjects factor was visuotactile stimulation and the between-subjects factor was diagnostic group). Comparing the AN and HC groups, the main effect for type of visuotactile stimulation on embodiment was significant $F(1, 93) = 81.3$, $p < .001$, with significantly greater embodiment scores in the synchronous versus the asynchronous condition. The main effect for diagnostic group was also significant $F(1, 93) = 6.3$, p = .014, such that the AN group reported experiencing embodiment significantly more strongly than the HC group. However, the interaction between type of visuotactile stimulation and diagnostic group was not significant $F(1, 93) = .1$, p = .763. Controlling for mood using ANCOVA revealed a significant main effect for visuotactile stimulation $F(1, 91) = 28.9$, $p < .001$, but a non-significant main effect for diagnostic group $F(1, 91) = .5$, p = .504 and a non-significant interaction between visuotactile stimulation and diagnostic group $F(1, 91) = .2$, p = .691.

Comparing the BN and HC groups, the main effect for type of visuotactile stimulation on embodiment was significant $F(1, 80) = 75.4$, $p < .001$, as was the main effect for diagnostic group $F(1, 80) = 5.3$, p = .024. Thus, significantly greater embodiment scores were reported in the synchronous versus the asynchronous condition and the BN group reported experiencing the illusion (i.e., embodiment) significantly more strongly than the HC group. However, the interaction between type of visuotactile stimulation and diagnostic group was not significant $F(1, 80) = .9$, p = .358. Controlling for mood using ANCOVA did not change these findings.

DISCUSSION

The aim of this study was to examine the bodily self in eating disorders by using the RHI paradigm and examining its relationship with eating disorder psychopathology. The primary hypothesis that individuals with an eating disorder will have greater susceptibility to the RHI was supported: participants with an ED experienced the RHI significantly more strongly than HC individuals. The second hypothesis was also supported, such that individual differences in the experience of the RHI, both perceptually and cognitively, were related to eating disorder psychopathology and the experience of the RHI was significantly predicted by interoceptive deficits and self-objectification.

The findings from this study indicate that the experience of the bodily self is more plastic in individuals with an eating disorder given that they experience the illusion more strongly than controls. This finding held for both perceptual (proprioceptive drift) and cognitive (questionnaire) measures of the RHI. Interestingly, this increased sensitivity of those in the eating disorder group occurred generally, rather than specifically in the synchronous condition. As outlined in the Introduction, the first aspect of body perception underlying the RHI common to both the synchronous and asynchronous conditions is visual capture (hand in a posture and location coinciding with one's real hand), while the second aspect is multisensory integration (temporal and spatial congruence of seen and felt touch). As it was found that the eating disorder group was significantly different from the healthy controls irrespectve of the visuotactile induction condition (i.e., whether it was synchronous or asynchronous), suggests that eating disorders are associated with a heightened sensitivity to visual capture, rather than heightened sensitivity to multisensory integration. This result suggests that the body image of people with ED shows heightened plasticity when visual information about the body conflicts with other cues, such proprioception, interoception, and high-level beliefs.

The findings of this study also demonstrated that both perceptual (proprioceptive drift) and cognitive (questionnaire) measures were related with each of the self-report eating disorder psychopathology measures, except for Bulimia. Approximately 20% of the variance in the experience of the illusion could be accounted for by eating disorder psychopathology. In particular, interoceptive deficits and self-objectification were significant predictors of embodiment, a result consistent with previous research [9]. Specifically, the relationship found in the present study between self-objectification and the RHI is consistent with the relationship between internalisation of sociocultural standards and the RHI found by Mussap and Salton [9]. Self-objectification and internalisation of sociocultural standards can be interpreted as similar constructs, given that self-objectification is a sociocultural factor in which women learn to value observable and physical body attributes, rather than non-observable attributes and abilities [17]. Previous research has found self-objectification to be associated with reduced interoception and self-awareness [17,20]. Additionally, a recent study that examined in healthy individuals the relationship between interoception and embodiment using the RHI task found that interoception modulated embodiment, such that reduced interoceptive sensitivity was associated with a stronger experience of the illusion [21]. In the present study, we also found that increasing interoceptive deficits were related with a greater experience of the illusion, in both perceptual and cognitive domains. Thus, it may be that viewing oneself more from an appearance-based perspective, namely self-objectifying, distorts the interoceptive experience of the bodily self, or vice versa. Both interoceptive sensitivity and self-objectification merits further investigation, especially as the interoceptive deficits predictor used in this study was an 8-item questionnaire subscale of the EDI-3 and more refined measures of this concept, including experimental measures of interoceptive sensitivity, could be used and may account for a greater amount of variance.

Clinical implications and future research

The overall findings of the present study in conjunction with those of previous research provide support for the model we have proposed [22] that there is a disturbed experience of the bodily self in individuals with an eating disorder. In particular, the findings indicate that affected individuals demonstrate increased sensitivity to the visual, rather than multisensory, aspects of body perception and that interoception and self-objectification may be key factors in the proposed disturbance. Such a body-specific visual hypersensitivity in affected individuals, and not a general sensory or visual processing problem, may play an important role in the key characteristic of body image disturbance in eating disorders, and shed light on the aetiology and maintenance of this disturbance that could in turn be targeted in treatment.

To date, the underlying basis of body image disturbance in eating disorders as cognitive, emotional or perceptual processing problems, has not been clearly distinguished. However, these findings indicate that perceptual processes are involved and may play an important aetiological and maintenance role that could be targeted to improve treatment. With respect to enhancing current treatment approaches, because it appears that individuals with an eating disorder have a heightened sensitivity in which vision dominates interoceptive bodily signals, developing targeted techniques to increase awareness and accuracy of interoceptive processes is worthy of further research. This could include developing such remediation approaches as attentional training to interoceptive bodily signals, particularly of touch and proprioception, as indicated to be specifically disturbed from the findings of this study.

Furthermore, the finding in the present study of an association between the RHI and self-objectification indicates cognitive and sociocultural processes are also involved in the disturbed experience of the bodily self in individuals with an eating disorder. That is, processing the body more from a third-person (rather than first-person) perspective may account to some extent for the development of this disturbance. Therefore, needing further investigation is the tendency of individuals with an eating disorder to engage in excessive self-objectifying cognitive processes as a noteworthy target to be addressed in treatment of body image disturbances.

Finally, as the RHI task is simple to administer, it could be used as an assessment tool to assess somatosensory information processing in individuals with an eating disorder and to index improvement from therapies designed to correct inaccurate body perceptions [9]. However, further research examining the RHI in individuals who have recovered from an eating disorder is also necessary to help identify whether this disturbance of the bodily self is a vulnerability trait for eating disorders or if it is confined to the period of illness.

Conclusion

To our knowledge, this is the first study that has examined the bodily self using the RHI paradigm in a clinical sample of individuals with an eating disorder. This study provides initial support for increased plasticity of the bodily self in people with an eating disorder as it found that affected individuals experience the RHI more strongly than healthy controls in both the perceptual and cognitive aspects of the paradigm. These findings provide support for the model we have suggested previously [22]. They also indicate that somatosensory information processing of the body may be reduced in people with an eating disorder, or visual information about the body may be excessively attended to, or both. With further research, these findings may contribute to our understanding of the aetiology and maintenance factors involved in eating disorders, such as perceptual body processing, interoceptive deficits and self-objectification, and the experience of the bodily self.

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TABLE/FIGURE LEGENDS

Table 1: Participant demographics and clinical details and comparisons with HC

Table 2: Correlations (Spearman's rho) between synchronous RHI measures and clinical measures.

Table 3: An examination of the predictors of the RHI (i.e., synchronous embodiment score)

Figure 1: *Rubber hand illusion apparatus. In this view, the box lid is lifted up, so the participant can view the fake hand and the experimenter is out of sight.*

Figure 2: Mean and standard error of proprioceptive drift in each group for each RHI condition. Error bars represent ±1 standard error of the mean.

Figure 3: Mean and standard error of embodiment score in each group for each RHI condition. Error bars represent ±1 standard error of the mean.