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RESEARCH ARTICLE

Diminished size–weight illusion in anorexia nervosa: evidence for visuo-proprioceptive integration deficit

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Abstract Individuals with anorexia nervosa (AN) experience pronounced body image distortion in combination with a pernicious desire to maintain a dangerously low body weight. Relatively little is known, however, about the mechanism underlying body image distortion in AN. Despite having normal visual perception, individuals with AN both feel and see themselves as large-bodied and show deficits in interoception and haptic perception, suggesting a potential deficit in visual and tactile integration. The size–weight illusion (SWI) arises when two objects of equal weight but different sizes are held. Typical individuals experience a strong and robust illusion that the smaller object feels much heavier than the larger object because of an implicit assumption that weight scales with size. The current study compared the strength of the SWI in individuals with AN to healthy control participants. Individuals with AN exhibited a markedly reduced SWI relative to controls, even though their ability to discriminate weight was unaffected. Because the SWI is strongly modulated by visual appearance, we believe our finding reflects decreased integration of visual and proprioceptive information in anorexia. This finding may explain the puzzling observation that visual perception of the body in a mirror does not correct an AN patient's distorted body image. We speculate that methods to correct visuo-proprioceptive integration in constructing body image may help rehabilitate patients' judgments of size and weight regarding their own bodies. We also suggest that a dysfunction in interactions between inferior parietal lobule (concerned with body image), insula, and hypothalamus may underlie AN.

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Introduction

Anorexia nervosa (AN) is a serious—potentially fatal—psychiatric disorder, with a standardized mortality rate as high as 10.5 (Birmingham et al. 2005). The average prevalence found in reviews of anorexia is about 0.3% for young females (Hoek and van Hoeken 2003). Prognosis for patients with AN is poor; Zipfel et al. (2000) found only a 50.6% rate of full recovery for patients with AN 21 years after hospitalization, while 10.4% still met full criteria for AN.

Severely distorted body image is a diagnostic feature of AN. Despite exhibiting normal perceptual sensitivity to body size (Smeets et al. 1999), individuals with AN both feel and see themselves as large-bodied. Indeed, body size overestimation in anorexia predicts pretreatment characteristics that are associated with poor outcome, including greater denial of illness (Casper et al. 1979). Current explanations of anorexia propose multifactorial models including genetic, biological, psychological, and socio-cultural risk factors related to disturbances in neurotransmitter and neurocircuit function (Kaye et al. 2009). Differences in serotonin receptors may relate to increased satiety and an anxious, harm avoidant temperament in individuals susceptible to AN. Little is known, however, about the biological basis of the profound body image distortion that is a core symptom of the disorder—or its resistance to correction through sensory feedback.

Striking parallels between body size overestimation in anorexia and body image distortion in patients with right superior parietal lobule (rSPL) damage have been noted by a number of authors (e.g. Tomasino 1996). The rSPL is associated with multisensory construction of body image. Damage to the right parietal lobule can cause unilateral neglect, denial of paralysis (anosognosia), or misattribution of a paralyzed limb to another person (somatoparaphrenia; Critchley 1953). Right parietal dysfunction has also been associated with hatred of the left side of the body and with the desire to amputate a healthy limb that inexplicably feels over-present or unnatural (McGeoch et al. 2011). Individuals with anorexia similarly exhibit body image distortion and denial about the state of their body.

Indeed, a number of studies have now reported differences in right parietal function in anorexia. Komatsu et al. (2010), for instance, found decreased regional blood flow in the right parietal lobe of AN patients, which was restored after recovery. Nico et al. (2010) compared AN patients to patients with right and left parietal damage, as well as healthy controls, on a task probing implicit body representation. Interestingly, both patients with AN and *right*, but not left, parietal patients showed selective distortion of their left body boundary when judging whether an approaching visual stimulus would contact their body. Finally, Guardia et al. (2010) found that AN patients had enlarged implicit body schema in a task judging whether they could fit though apertures of various widths. This suggests that distortions of body image in AN are at least in part lower-level distortions of representation and may be related to disturbances of the rSPL.

These findings suggest disturbances in AN in sensory integration related to body image representation. Could basic problems with sensory integration underlie these distortions? How could body representation of the self be selectively distorted, particularly if visual perception of other bodies is normal? A possible answer is that interoception and proprioception are unique to ones own self, so distortions in these somatosensory domains may lead uniquely to distortions of ones own body representation (one has visual access to other bodies, but interoceptive access only to oneself). Indeed, differences have been found in individuals with AN in haptic perception; Grunwald et al. (2002) found that patients with AN had difficulty reproducing angles through haptic perception. Patients with AN have also been found to have reduced interoceptive awareness that is improved with recovery (Fassino et al. 2004; Matsumoto et al. 2006), and reduced interoceptive sensitivity (reduced capacity to accurately perceive bodily signals, e.g. Pollatos et al. 2008).

Yet distortions of proprioception and interoception alone cannot explain why patients with anorexia process visual images of their own body differently from images of other bodies. Sachdev et al. (2008) showed abnormal processing of self-images in anorexia using fMRI. Self-image processing lacked activation of the attentional system or insula seen in healthy participants. Similarly, Blechert et al. (2010) demonstrated attentional bias for self-photographs in anorexia. We can explain such differences, however, if we consider disturbances in multisensory integration. Higher-level visual distortions might result from multisensory construction of body image in the right parietal lobule based on distorted proprioception and integration of visual and proprioceptive information. Indeed, patients with AN have difficulty drawing objects that they explore through touch (Grunwald et al. 2001). While the authors explain this finding in terms of deficits in haptic perception, the finding could equally well reflect deficits in tactile-visual transformation. Patients in the same study also show diminished parietal activation during the task, suggesting proprioceptive integrative deficits in the parietal lobes. Similarly, Mohr et al. (2010) conducted fMRI imaging of body size estimation in AN patients and suggest that body size overestimation may relate to difficulty retrieving multimodal body schema in the precuneous/posterior parietal cortex. Difficulties with retrieval might also reflect disturbances of body representation; Epstein et al. (2001) found subtle neurocognitive deficits involving executive functions in addition to body-schema-related functions during acute stages of AN. Interestingly, AN has recently been noted to share many social and cognitive endophenotypes with autism (Zucker et al. 2007), a disorder that involves significant deficits in sensory integration (e.g. Russo et al. 2010; Oberman and Ramachandran 2008). Might disturbed sensory integration involving touch, proprioception, and vision constitute an endophenotype of AN?

We tested visuo-tactile-proprioceptive integration in individuals with AN and healthy control participants through a size–weight illusion (SWI) battery. The SWI, first known as the "Charpentier Illusion," is a powerful demonstration of the predictive power of visual perception. The participant is given two objects of identical shape and absolute weight (mass) but different sizes and asked to compare their weights. Participants consistently estimate the smaller of two equally weighted disks to be heavier (Charpentier 1891). Even when the larger disk is 50% heavier than the smaller one, typical individuals experience a strong and robust illusion that the smaller object feels heavier because of an implicit expectation that weight scales with size. Intriguingly, we have found that the illusion does not diminish even if the participant is explicitly told that the objects are of equal weight; the illusion is thus relatively immune to top-down correction.

The SWI results from higher-level perceptual integration of vision and tactile perception (Flanagan and Beltzner 2000). Previous research has indicated that sensorimotor

(Ross 1966; Ross and Gregory 1970), perceptual (Flanagan and Beltzner 2000; Grandy and Westwood 2006), and cognitive (Ellis and Lederman 1998) components all contribute to the illusion. Disagreement exists, however, as to the relative influence of sensory versus cognitive mechanisms. Flanagan and Beltzner (2000) showed that fingertip force scales to actual weight with practice, suggesting independence of sensorimotor systems from higher-level perceptual systems in which the illusion is preserved. Grandy and Westwood (2006) similarly found that perceived heaviness of objects in the SWI did not change even as participants used sensorimotor feedback to correct their lifting force. Indeed, Buckingham and Goodale (2010) found that looking at objects before lifting them—without actually seeing them during lifting—can create a SWI, demonstrating that visual expectation alone can alter perception of weight and maintain inaccurate lift behavior. Similarly, Kawai et al. (2007) demonstrate that a SWI influenced only by illusory visual cues is sensory based and depends on participants' multimodal sensory integration. Finally, Ellis and Lederman (1993) have documented an SWI arising from haptic perception alone, showing that visual cues are not the only origin of the SWI. Clearly, the SWI can be influenced by tactile sensation, vision, and expectation.

Based on our theory about multisensory body representation disturbances in AN, we predicted decreased SWI in patients with AN. Decreased SWI would suggest diminished multisensory integration between touch, proprioception, and vision.

Methods and materials

Participants

Ten females with *anorexia nervosa* [AN patients; mean age 29.1 ± 11.0 years; mean body weight index (BMI) 17.1 ± 0.9; median illness duration 36 months] and ten females without any eating disorder (control participants; mean age 25.8 ± 9.0 years; mean BMI 21.7 ± 1.6) participated in this study. All participants provided informed consent to participate in the current study.

Anorexia nervosa patients were recruited through local psychologists and eating disorder outpatient providers. Patients had a DSM-IV-TR diagnosis (American Psychiatric Association 2000) of AN made by a licensed clinical psychologist (one patient unwilling to seek treatment was screened by the experimenter, and results were reviewed by a clinical psychologist) and were currently underweight (BMI < 18.5). Participants were excluded if they had any known neurological disorder or psychotic illness. Control participants were additionally screened for any past or present psychological disorder using the MINI (Sheehan et al. 2009). Control participants also participated in an interview to screen their lifetime relationship with weight and food. Participants were included in the study if they showed no psychological disorders past or present, no history of underweight or overweight, a current BMI in the normal range, no history of dieting to lose more than 10 pounds, and a self-reported daily eating pattern than exhibited no restrictiveness or excessive concern about eating. Control participants were also excluded if any member of their immediate family had been diagnosed with an eating disorder.

Size–weight illusion

The SWI was measured by asking participants to judge the relative absolute weight (heaviness) of sequentially presented pairs of wooden disks painted gray. Participants were presented with one small disk (3.8 cm tall and 5.1 cm diameter) and one large disk (3.8 cm tall and 12.7 cm diameter) on SWI trials, and with two large disks on control trials. The surface area of the large disk was four times greater than the surface area of the small disk. The weight of each disk was evenly distributed about its center, and disks appeared to be of identical material.

Participants were instructed as follows: "during this experiment, you will be asked to compare the weights of two disks that I place on your palms, one in each hand. Please tell me numbers from 1 to 10 that describe the relative weights of the disks; that is, how much they weigh compared to each other. For example, if one is twice as heavy as the other, you could say 'two and one' or 'eight and four.' You can use different numbers on each trial—all that matters is that for each pair of disks you pick numbers that compare their weight. Please keep your eyes on the disks the whole time."

During testing, the experimenter placed two disks simultaneously onto participants' outstretched hands (see Fig. 1). If participants closed their eyes or looked away from the disks, they were immediately reminded to look back at them.

Fig. 1 Presentation of SWI disks. On SWI trials, the participant held a small-sized disk weighing 90 g and a large-sized disk weighing 90–210 g. The participant watched the disks at all times and generated estimates of the weight of each disk relative to the other

Size–weight illusion trials presented the 90-g small disk to one hand and one of 13 large disks (90–210 g in 10 g increments) to the other. Four blocks were conducted; each contained all thirteen SWI trials in one of five pseudo-random orders. The participant was not informed that the small disk was always the same one. In addition, each block contained four intermixed weight discrimination trials in random order: 100–130, 100–150, 100–190, and 100–210 g. Blocks counterbalanced presentation of the small disk (or lighter disk, on control trials) to the participant's right versus left hand.

Statistical analyses

For each SWI trial, a SWI ratio was obtained by dividing the number the participant assigned the small disk by the number the participant assigned the large disk. Ratios greater than one indicate that the participant judged the small disk to be heavier than the large disk; in reality, the small disk was always of equal or lesser weight than the large disk. SWI ratios were averaged across blocks for each subject, and the log of each average ratio was calculated for use in subsequent analyses to linearize the distance between the ratios. For one participant with AN, data from the first of the four blocks administered were dropped because the estimates provided by the patient were highly anomalous and inconsistent with the much more consistent responses she provided on the three subsequent blocks.

The control weight discrimination trials were analyzed similarly to the SWI trials by dividing the participant's estimate of the lighter disk's weight by the participant's estimate of the heavier disk and evaluating the log of this ratio. Difference scores were calculated by subtracting actual from estimated average log ratios and compared between groups. The absolute value of this difference score was used as a measure of weight discrimination accuracy. The Pearson product-moment correlation between weight discrimination accuracy and SWI was checked, as some groups have found a positive correlation between weight discrimination and susceptibility to SWI (e.g. Kawai et al. 2007).

Amazeen and Turvey (1996) found that the perceived heaviness of objects decreases with constant mass but increasing volume and increases with increasing mass but constant volume. This suggests that comparison of disks with equal volume but differing mass creates a "reverse" SWI itself wherein the discrepancy between a visual-based expectation of equivalent mass and an actual mass difference is amplified. In the traditional SWI, the small weight is denser than in appears, causing it to feel heavier; in the reverse case, one disk is less dense than it appears, leading to an illusion that it is lighter than it actually is. We realized post hoc that a comparison of directional error on our control weight discrimination task afforded a reverse SWI illusion, and we hypothesized that AN patients would also exhibit a reduced reverse SWI, due to decreased relative reliance of vision. To check this, we compared directional difference scores between groups to determine whether either group tended to globally over- or underestimate mass differences and whether they experienced a "reverse SWI" based on the discrepancy between vision and weight on these trials.

A repeated measures ANOVA (within-subject factor: disk ratio; between-subject factor: group) was conducted to test the prediction that the log of SWI ratios would differ in AN patients and healthy controls. Finally, we also conducted Pearson product-moment correlations to test whether illness duration or current BMI was correlated with SWI.

Results

Weight discrimination

Weight discrimination data were missing for two AN patients who participated before these trials were added to the study. Unfortunately, these participants were not available to return to the laboratory in the period of illness during which they met our inclusion criteria. In the remaining participants, we found that the absolute value of average difference scores did not differ between AN patients and controls ($t(16) = 0.2129$, $P = 0.8341$). In other words, the groups exhibited similar levels of accuracy in mass discrimination. Weight discrimination errors showed a trend toward positive correlation with SWI in controls Pearson product-moment correlation; ($r(8) = 0.564$, $P = 0.090$). In contrast, AN patients showed a negative correlation between weight discrimination errors and SWI ($r(6) = -0.681$, $P = 0.063$). These correlations were significantly different from each other ($z = 2.51$, $P = 0.012$).

Healthy subjects

Healthy controls exhibited an SWI profile similar to that found in other studies: the SWI diminished as the actual weight difference between the disks increased. For example, the point of subjective equality (the point at which subjects are equally likely to report that one weight is heavier than the other, and therefore cannot discriminate between the two stimuli; see Gescheider 1997) for healthy participants in the current study was estimated from a moving average trendline to occur at a large disk weight of approximately 177 g; using the same stimuli, Williams et al. (2009) found a point of subjective equality of 174.2 g for nonpsychiatric individuals.

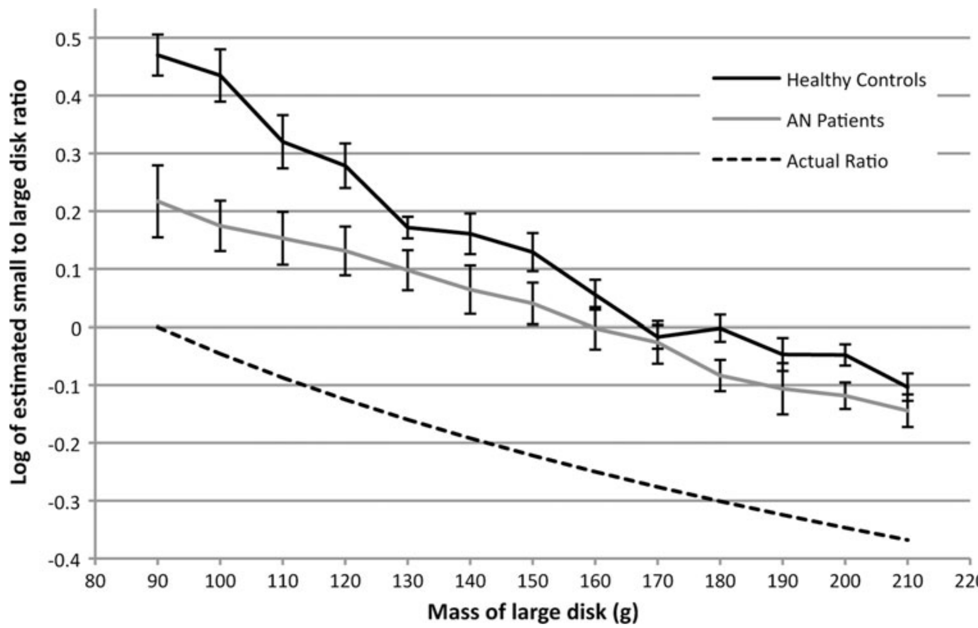

Fig. 2 Log of SWI ratios by trial type in AN patients and healthy controls. Higher small to large disk size–weight ratios indicate greater illusion of perceiving the smaller disk as heavier when it actually was not. The higher the log size–weight ratio from the actual log weight ratio of the disks (*dashed line*), the greater the illusion perceived

AN patients

Like the healthy controls, AN patients showed a SWI on all trials pairs (average SWI ratio grater than actual disk weight ratio on all trials; see Fig. 2). However, their SWI was reduced compared to healthy controls (see Fig. 3). The point of subjective equality for AN patients was approximately 166 g compared to 177 g for the healthy controls. To avoid losing two patient cases, the two missing control trial values were replaced with the mean of all study participants. The (disk weight ratio × group) ANOVA with weight discrimination as a covariate showed a significant main effect of group, $F(1,17) = 7.164$, $P = 0.016$. The main effect of group remained significant when the two cases with missing covariate data were excluded from analysis ($F(1,15) = 7.587$, $P = 0.015$). The η^2 (eta-squared) was 0.219, indicating a very large effect size of group on the SWI. The difference between patient and control participants was larger when the disks were closer in weight (see Fig. 2). Indeed, there was a highly significant interaction between group and disk weight ratio: Greenhouse–Geisser $F(5.000) = 5.364$, $P < 0.001$ ($P < 0.01$ without replacement of missing covariate data). This was driven by controls, whose SWI depended significantly on disk weight ratio $F(1) = 81.880$, $P < 0.01$). Disk weight ratio did not affect AN patients' SWI estimates ($F(1) = 0.289$, $P = 0.592$).

Within the AN patients, SWI was not correlated with illness duration ($r(8) = 0.421$, n.s.) or current BMI ($r(8) = -0.011$, n.s.). Because a number of our patients were actively participating in treatment programs, however, it is possible that other measures of illness severity might be predictive of SWI, as BMI might not accurately represent recent illness severity, and illness duration similarly might not predict current severity.

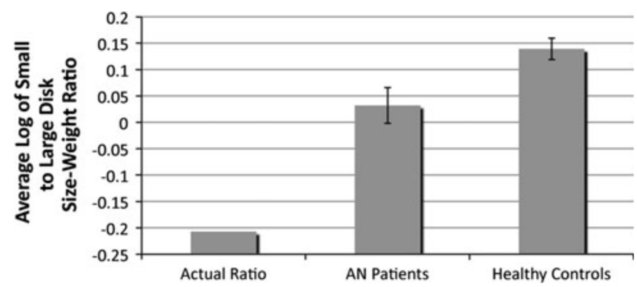

Fig. 3 Log of SWI ratios in AN patients and healthy controls. AN patients and healthy controls estimated the weights of small disk and large disk pairs of varying relative weights. Visual information about disk size creates a "size–weight illusion" that the smaller disk is heavier than it actually is. Estimated weight ratios of the small to large disks were averaged and linearized using a log transform. Higher log size–weight values indicate greater illusion of perceiving the smaller disk as heavier when it actually was not

"Reverse" SWI

Directional difference scores on the weight discrimination trials did differ significantly between AN patients and controls ($t(16) = 2.4548$, $P = 0.0259$). The difference for AN patients between log ratios of estimated and actual disk weights did not differ from zero ($t(7) = 0.6846$, $P = 0.5156$), demonstrating that the errors AN patients made were bidirectional and not skewed either toward or away from errors expected by visual expectation. Difference scores between estimated and actual log ratios for controls, on the other hand, did differ significantly from zero ($t(9) = 3.1156$, $P = 0.0124$); their errors were significantly biased in the direction of visual expectation. Thus, while patients and controls did not differ in magnitude of error on weight discrimination trials, the directionality of their errors revealed a reverse SWI in controls.

Discussion

Individuals with AN exhibit deficits in interoception and haptic perception, yet their overall body image remains highly distorted even if flatly contradictory information is provided through visual feedback (e.g. viewing their body in a mirror). As such, the disorder provides an opportunity to explore how "low-level" sensory operations can influence high-level percepts and even "beliefs" about ones self-image, and vice versa (Ramachandran et al. 2009).

In the current study, patients with AN exhibited a markedly reduced SWI (and reduced "reverse" SWI) relative to controls—despite normal weight discrimination ability. Could these effects be due to an overall bias in either group to underestimate or overestimate weight differences? One could worry that a general tendency to exaggerate weight differences might drive the differences in SWI. However, controls' errors on the regular SWI trials reflect greater *overestimation* of the lighter weight than AN patients exhibit; this is the opposite of control trials, where controls *underestimate* the mass of the lighter weight more than AN patients do. This inconsistency demonstrates that controls do not differ from AN patients in their magnitude of errors or in their sensitivity to mass discrepancies; they differ only in that their errors are consistent those predicted by visual expectation.

The SWI illusion tends to be higher at more equivalent disk masses because the real weight difference is less discriminable and hence the conflict with visual appearance is smaller. Indeed, literature on multisensory processing confirms that multisensory processing is heightened under conditions of sensory uncertainty (e.g. Alais and Burr 2004). In the current study, controls showed higher relative SWI when the disks were closer in weight. AN patients, however, demonstrated a more consistent level of illusion throughout the study. We believe this difference arises because the SWI is stronger for controls and thus also differentially stronger under optimal conditions for the illusion.

We believe that the SWI effects in the current study are best accounted for by cross-modal sensory integration explanations (e.g. Anderson 1970). Because the SWI is strongly modulated by visual appearance, our finding probably indicates reduced reliance on visual input in judgments of weight by AN patients, relative to a greater reliance on proprioceptive information. It is also possible, however, that patients rely to a lesser extent on the tactile cues that also conflict with the mass cues. Indeed, Keizer et al. (2011) recently reported tactile body image disturbances in anorexia; patients overestimated distances between tactile stimuli on both the arm and abdomen. Overestimating the tactile size difference between the weights in the current study, however, ought to increase the SWI rather than decrease it. Further, the SWI tends to remain quite strong even when tactile cues are removed (Kawai et al. 2007). Thus, we suspect that visuo-proprioceptive integration is more likely disturbed and focus our discussion on this theory, but tactile-proprioceptive or visuo-tactile-proprioceptive integration differences are also possible. Abnormality in visuo-proprioceptive integration may mean that AN patients utilize a different strategy than healthy individuals in judging their own weight and size.

Why would patients with AN show a relatively greater reliance on proprioceptive information? One possibility is that visual processing is impoverished in AN. This is unlikely given the lack of basic visual perceptual differences found to date in AN, and the fact that visual body distortion tends to be selective for images of the self. However, it is possible that malnutrition could affect either vision or sensory integration; it has been found that rats undernourished in early adult life exhibit delays in neuronal pruning in visual cortex (Warren et al. 1989). There is one report that right visual field presentation of objects results in a general size overestimation in women, and that this overestimation is much greater for bodies than for objects (Mohr et al. 2007). Such distortion might plausibly be exaggerated in AN but would still not make perception more variable and hence less reliable. Disks in the current study were counterbalanced to the right and left hands of participants, so differences in visual field should not affect the current results. Thus, there is no evidence to our knowledge of diminished consistency of object perception that could explain diminished reliance on this sensory domain in the current data.

Another possibility is a preference for proprioceptive information. This could not be due to increased accuracy of proprioceptive information, as patients and controls were equally good at the weight discrimination task. However, it is possible that patients rely more on proprioception in general due to increased sensitization to feelings of "fatness" or density of the body. Normally sensory processes are relied upon more when they are more accurate, but cognitive-emotional processes can also bias sensitivity to one domain, as presumably occurred in Mohr et al. (2007). If proprioceptive information about the body becomes distorted (along some dimensions, such as body size or density) and is prioritized over information from other senses, this would explain why patients feel fat and why this sensation might dominate body image perception. Another reason why distortion is likelier to occur in proprioception than vision is that we have a proprioceptive sense primarily of our own bodies, but we have a visual sense of both our own body and that of others. Since anorexia affects primarily the sense of ones own body, proprioception would seem a more likely candidate for sensory disturbance. It is also possible that deficits in interoception (e.g. Pollatos et al. 2008) lead the brain to prioritize this information when it is available.

In contrast to our prediction, but in line with this reasoning, AN patients and controls showed significantly different relationships between weight discrimination accuracy and SWI. Weight discrimination accuracy was negatively correlated with the SWI in controls, suggesting that more accurate proprioceptive information was relied upon more than less accurate proprioceptive information. In contrast, AN patients relied more on proprioceptive information when it was inaccurate, obtaining a lower SWI with reduced weight discrimination accuracy. This could reflect a disturbance in evaluating the accuracy of sensory information in AN patients.

A further possibility is that sensory integration in general is disturbed in anorexia. General sensory integration problems in anorexia could to do with effects of starvation affecting white matter connectivity, or with top-down effect of beliefs about body image biasing normal construction and updating of body image. Finally, SWI differences could be attributed to differences in how AN patients and controls utilize visual and proprioceptive information to generate expectations of heaviness. In other words, sensory integration per se might not be disturbed, but AN patients might have different internal models of heaviness that would lead to different expectations based on visual information. While we favor a sensory interpretation of our data given the previously discussed sensory disturbances found in AN and data favoring sensory interpretations of the SWI (e.g. Kawai et al. 2007), we hope that future work will be able to disentangle the effects of sensory, sensory integration, and cognitive expectation differences that may exist in AN.

A reduced SWI in patients with AN fits with emerging picture of interoceptive and proprioceptive deficits in this population, but our evidence points more specifically to dysfunctional multisensory integration. This would explain how visual body image distortions can occur in the absence of low-level visual deficits and may also explain deficits in implicit body image and body schema found in relation to parietal lobe functioning (e.g. Nico et al. 2010; Guardia et al. 2010; Grunwald et al. 2001). Reduced SWI also implicates the parietal lobes; Jenmalm et al. (2006) found parietal, motor, and cerebellar activation involved in the comparison of predicted and actual sensory input during a lifting task. Right parietal dysfunction has been observed in anorexia (e.g. Nico et al. 2010; Grunwald et al. 2001) and seems to be correlated with illness state (Komatsu et al. 2010). Other brain areas are involved in the SWI as well, however; Chouinard et al. (2009), for example, found the activation of the ventral premotor area in relation to perceived heaviness based on density. AN may reflect dysfunction in interactions between sensory integration in the inferior parietal lobule (concerned with body image), affective processing of bodily states in the insula, and regulation of appetite through the hypothalamus (e.g. Ramachandran et al. 2009). Future work will need to determine whether sensory integration deficits exist between other sensory domains or whether they are restricted, as we would predict, to those involving proprioception and somatosensation.

One potential limitation of the current study is that participants were not explicitly tested on their ability to discriminate the visual size of the large and small objects. Differences in this ability could lead to differences in density expectation based on visual input. However, the lack of crude differences in visual sensitivity to size in patients with AN (Smeets et al. 1999) makes this an unlikely explanation for our finding. Another limitation is that we did not disentangle the contributions of vision and haptic perception to the SWI. While controlling for mass discrimination points toward an effect of vision, the SWI is also affected by haptic size cues. We plan to separate the effects of vision and haptic perception on weight judgments in future work.

The current finding may begin to explain how it is that direct visual perception of the body in a mirror does not correct an AN patient's distorted body image. Of course, the reduction in visuo-proprioceptive integration found in the current study is unlikely to fully account for the magnitude of perceptual disturbance seen in AN with respect to the patient's own body. Our finding may be one of multiple sensory or sensory integration disturbances present in AN, and indeed, we would expect that these differences would be stronger for processing of cues about ones own body, as it is generally self-perception that is most distorted in AN. Future research should examine whether distortions of a similar nature occur for judgments about the patient's own size and weight, and whether these correlate with severity of the eating disorder. If they do, then visual or visuo-tactile integration therapies might help rehabilitate perception of body weight and size in AN patients.

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