Manipulating body representations with virtual reality: clinical implications for anorexia nervosa

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Abstract

Anorexia nervosa patients exhibit distorted body representations. Specifically, they represent their bodies as *larger than reality*. Given that this distortion likely exacerbates the condition, there is an obligation to further understand and, if possible, rectify it. In pursuit of this, experimental paradigms are needed which manipulate the spatial content of these representations. In this essay, I discuss how virtual reality technology—implementing full body variants of the rubber hand illusion—may prove useful in this regard, and discuss some issues related to the clinical application of this method.

Interviewer: Has the risk of death been mentioned?
"Yeah."
Do you believe these things you've been told?
"No."
About the risk of death, do you think it could happen?
"Not to me."
That's the opinion of doctors, and I wonder why you don't think it can happen to you.
"Because you have to be really thin to die, and I'm fat, so it won't happen to me." (Tan et al., 2006, p. 7)

1. Introduction

While doubt remains over the extent of false body size beliefs in anorexia nervosa (AN) (Gutiérrez & Carrera, 2016), many patients (like the above) do undoubtedly believe they are "fat" or, at the very least, not excessively thin (Hartmann, Thomas, Wilson, & Wilhelm, 2013; Konstantakopoulos et al., 2012; Mountjoy, Farhall, & Rossell, 2014; O'connell et al., 2017). Further—as the above excerpt also reflects—it is reasonable to assume that such beliefs have a deleterious effect on recovery. In this essay, I suggest a possible way in which we might attempt to treat such beliefs.

The starting point for this suggestion is the recently proposed *empiricist* account of false body size beliefs in AN (Gadsby, 2017a). The guiding methodological principle of empiricist models can be traced back to Maher (1974), who, contrary to the prevailing theories of the time, suggested that delusional beliefs might arise as rational responses to particularly unusual experiences. This idea has been incredibly influential, giving rise to what have been termed the empiricist models. Empiricist models seek to identify the abnormal experiences which delusional patients suffer from which might act as the proximal cause of their beliefs, along with the cognitive and neurological deficits that give rise to such experiences (Coltheart, 2007).

To illustrate the approach, consider the case of Capgras delusion—the belief that a loved one has been replaced by an imposter. The standard empiricist model of this delusion refers to a dual-route mechanism for visual processing of faces: one route underpins the *recognition* of a familiar face, the other underpins the *affective response* (Ellis & Young, 1990). Capgras is then suggested to involve a breakdown in this system, such that the recognition route is intact, while the affective route is dysfunctional. This gives rise to a particular kind of abnormal experience: "conscious recognition of the identity of a face but absence of the affective response that characteristically accompanies the perception of a familiar face" (Coltheart, 2007, p. 1047). This experience of recognising the loved one's face, absent the usual affective response is thus proposed to cause the belief that they have been replaced by an imposter.

This explanatory approach has recently been adapted to understanding the false body size beliefs of AN patients. Specifically, a number of false experiences of body size have been identified, whereby patients experience their bodies as *larger than reality*. Further, the cognitive factors which give rise to these experiences have been identified as distorted body representations; patients cognitively *represent* their bodies as larger

than reality, causing them to *experience* their bodies as larger than reality (Gadsby, 2017b).

Though this empiricist approach is popular in modelling delusions, one might legitimately question the clinical importance of the models thus far proposed. Current empiricist models most commonly apply to the monothematic delusions of brain damaged patients, yet such cases are incredibly rare and the delusions usually abate without need for clinical intervention (Coltheart, 2007). This is in stark contrast to the case of AN, which is incredibly widespread and persistent, referred to as "one of the most frustrating and recalcitrant forms of psychopathology" (Vitousek, Watson, & Wilson, 1998, p. 391). What I will show is that, in the case of AN, the proposed empiricist model provides an important potential avenue for treatment.

I begin by discussing evidence of distorted body representations in AN—specifically, distortion of the spatial content of the *perceptual body image* and *body schema*. I then briefly review the hypothesis that the distorted spatial content of these two representations grounds false body size beliefs, through causing disturbed experiences of body size. Finally, I discuss the possibility of manipulating this content using virtual reality paradigms: full-body variants of the well-known rubber hand illusion. While this looks promising as a method of manipulation, in order to be clinically useful there are many further issues to resolve, a few of which I discuss.

2. Distorted body representations

First, some clarifying remarks on the target of interest. Devignmont defines body representations as internal structures that have "the function to track the state of the body and encode it, that can misrepresent it and that can be decoupled from it" (2018). There are thought to be a number of these internal structures, occupying various functional roles. However, there is significant disagreement and debate regarding their existence and nature—how many body representations exist, what their roles are and even what they ought to be named are all current subjects of debate (Carruthers, 2008; Pitron & deVignemont, 2017; Gadsby, 2017c; 2018a; Longo, 2015; de Vignemont, 2018). Nevertheless, we may avoid much of the controversy by clearly defining the body representations which are relevant for the empiricist model of AN and explicating how the content of such body representations can be measured.

2.1 Perceptual body image

Anorexia nervosa has a long association with the notion of body image disturbance (Bruch, 1962). While the term body image is often used to refer to a whole host of intentional objects of which the body is the target (Gallagher & Cole, 1995, p. 371), herein I focus on what's often referred to as the *perceptual* body image (Cash & Deagle, 1997). This is generally defined, following Schilder, as "the picture of our own body which we form in our mind, that is to say the way in which the body appears to ourselves" (Schilder, 1935, p. 11). Under this view, the perceptual body image is a representation of our own bodies which subserves mental imagery.

An important distinction to draw here is between the content of the *experience* of mentally picturing the body and the content of the *representation* which underpins this experience (Phillips, 2014). Although the two are directly related, the representational content is what's relevant to the empiricist model of AN (see footnote 2). As such, it's this content I will be referring to as the perceptual body image. Though this definition is perhaps distinct from Schilder's, it's nevertheless most appropriate for present purposes.

Traditionally, the size content of the perceptual body image has been measured using body size estimate (BSE) tasks. The specifics of these tasks vary, but generally involve comparing the size of a visual stimulus with either a body part, or the whole body (see below).[1] Crucially, these tasks are carried out without participants being able to see their own bodies. It's thus assumed that the tasks rely on a comparator process between the visually presented image and the participant's perceptual body image; misjudgement is then taken to be reflective of perceptual body image distortion (Smeets et al., 1999).[2]

The broad variety of BSE techniques adopted by AN researchers throughout the years has led to much disagreement and confusion in the field (Smeets, 1997), causing some to suggest abandoning the approach altogether (Hsu & Sobkiewicz, 1991). However, recent critical reviews and meta-analysis have validated these techniques, concluding that AN patients do exhibit oversized perceptual body images (Gardner & Brown, 2014; Smeets, Smit, Panhuysen, & Ingleby, 1997; Molbert et al., 2017; cf. Farrell, Lee, & Shafran, 2005;).[3]

One useful distinction to draw amongst BSE tasks is between *metric* and *depictive* methods (Longo & Haggard, 2012). Metric methods generally focus on particular body parts, showing participants a line and asking whether it is larger or smaller than the body part in question. In contrast, depictive methods generally show participants *depictions* of whole bodies; these are sometimes silhouettes or computer-generated images, often of the participant's own body, distorted in size.

According to an influential movement within body representation literature, a distinction can be drawn between the *explicit* perceptual body image and a number of *implicit* body representations (Longo, 2015; Longo & Haggard, 2010; 2012).

[1] Often times participants will take a more active role in the estimation process, drawing or marking out the distance of certain body parts themselves.

[2] Considering the assumptions behind such tasks also clarifies the target of interest as the representational, rather than experiential content. Participants needn't have any *conscious* experience of the two images being compared; rather, the process occurs entirely unconsciously, all participants become aware of is the resulting judgment (i.e. the presented body is smaller/larger than my own).

[3] For many, the debate over whether the BSE evidence thus far uncovered is truly indicative of perceptual body image distortion is still live (Mölbert et al., 2018; Moscone et al., 2017). However, I won't delve into these issues here. For now, I simply follow in the background assumption of the empiricist approach—also held by many AN researchers—that AN patients exhibit perceptual body image distortion.

Depictive BSE tasks are thought to directly measure the explicit perceptual body image, while the outcome of metric tasks is weighted by both explicit and implicit representations (Moscone et al., 2017).[4] The distinction between these measurement task types is important, as it's the *explicit* perceptual body image which is relevant to the empiricist model of AN (see section 2.3, footnote 4).

2.2 Body schema

Aside from perceptual body image distortion, further evidence has come to light suggesting that AN patients exhibit distortion of a distinct body representation: *the body schema*—a largely unconscious body representation, traditionally associated with holistic motor control (Engel & Keizer, 2017; Guardia et al., 2012; Guardia et al., 2010; Keizer et al., 2013; Metral et al., 2014; cf. Wignall et al., 2017). As in the case of the perceptual body image, it's thought that the *spatial* content of the body schema is distorted, representing patients' bodies as *larger than reality* (Gadsby, 2017c).

In order to flesh out the exact role body schema content plays in the motor system, I will introduce one of the motor circuits employed in motor control, the *inverse model* (Wolpert & Ghahramani, 2000). Inverse models take into account the current state of the body and calculate the motor commands needed to achieve the *desired* state. Whether assessing our ability to act, or initiating the action itself, the process begins with this inverse model step (Kawato, 1999). However, the commands required to enact certain movements (e.g. grasping for a coffee cup) will differ, depending on the agent's physical parameters (e.g. arm length). Therefore, in order to calculate body-appropriate motor commands, the inverse model must make use of information regarding the size and shape of the action relevant body parts, information stored in the body schema (de Vignemont, 2010, p. 673). While researchers use the term body schema in a number of different ways (Gallagher & Zahavi, 2007, p. 146), for present purposes, it can be defined as the representational content used by the inverse model in order to calculate body appropriate motor commands.

When passing through apertures, neurotypical subjects turn their shoulders at roughly the same shoulder-to-aperture ratio (Warren & Whang, 1987). They also conform to a shared ratio when assessing their ability to pass through apertures without turning their shoulders. Of course, this ratio is determined not by shoulder width directly, but rather by shoulder width as *represented* by the body schema—as both movement control and action assessment rely on body schema dimensions, via the inverse model (Gadsby & Williams, 2018).

Given this insight, a number of experiments were designed to measure the spatial content of AN patients' body schemas. Some asked participants to mentally simulate

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[4] Interestingly, while the explicit perceptual body image is thought to represent the surfaces of the body accurately, implicit representations exhibit routinely distorted spatial content (Longo, 2015). That said, this kind of widespread, non-pathological distortion isn't relevant here.

themselves walking through apertures, answering whether it would be possible without turning their shoulders (Guardia et al., 2012; Guardia et al., 2010; Metral et al., 2014). Others measured movement kinematics, recording the aperture size at which participants started to turn their shoulders (Keizer et al., 2013; Metral et al., 2014). Both kinds of studies report differences between patients and healthy controls: the ratio is higher for AN patients. This evidence is taken to suggest that AN patients' body schemas represent their bodies as larger than reality.

2.3 Oversized experiences

While there seems to be sufficient evidence to suggest AN patients exhibit distorted perceptual body images and body schemas, the question at hand is what role this distortion plays in the maintenance of the disorder. This is where the aforementioned empiricist approach is relevant, which claims that the false body size beliefs of AN patients are grounded by false experiences of body size—what have been termed *oversized experiences* (Gadsby, 2017a). Such experiences, it's suggested, arise from distorted perceptual body image and body schema content. As such, we arrive at an explanation for how this distortion plays a role in maintaining the disorder: through grounding harmful beliefs via oversized experiences.

The kind of oversized experiences which are said to arise from distorted perceptual body image content are *false body size comparisons*. As mentioned, when comparing one's body size with a visual stimulus (such as the sight of another body), a comparison is made with one's perceptual body image (Longo & Haggard, 2012). Further, self-comparison of body size is an act that those with eating disorders regularly engage in (Alleva et al. 2013, 99; Corning et al. 2006; Espeset et al. 2012, 524; Hamel et al. 2012). So, given the distorted size content of their perceptual body images, the outcome of these comparisons will often involve misjudgement, whereby they judge bodies that are wider than theirs to be thinner.[5]

Evidence suggesting this might be the case comes from the aforementioned depictive body size estimate tasks. In these tasks, AN patients do in fact judge images of wider bodies than their own to be thinner (Farrell, Lee, & Shafran, 2005; Smeets, Smit, Panhuysen, & Ingleby, 1997; Molbert et al., 2017). This suggests similar misjudgement would occur when comparing themselves with others. The empiricist model claims that such misjudgements provide feedback to the patients about their own body size—specifically, that they are *larger* than the body they are judging. These judgments don't constitute *direct* experiences of body size, however, they do bring to awareness false information about the body, of the form "my body is larger than theirs".[6] As such, if patients are (mis)judging those larger than them as in fact

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[5] Given that this involves comparison with vision of whole *bodies* (akin to depictive size estimation), only the dimensions of the *explicit* perceptual body image are relevant.
[6] The relationship between the experience of self-other comparison and awareness of body size information can be understood as a form of *inferential dependence* (Fulkerson, 2014, 86). Though patients don't *directly* perceive false bodily dimensions through such experiences, they do become aware of these dimensions in virtue of them (Gadsby, 2017b,

having *thinner* bodies, then this might plausibly ground beliefs about not being as thin as desired.

A different form of oversized experience involves the false perception of *affordances*. Affordances can roughly be defined as the actions provided by an environment (Gibson, 1979). Many affordances are determined by the size of one's body, for example, the aforementioned affordance of passing through apertures (face forward) is determined by the width of one's shoulders. Indeed, there are many such *size-determined* affordances which we encounter on a daily basis, such as fitting into clothes one sees, or through natural apertures between furniture or people in crowded places.

As discussed, the perception of these kinds of affordances relies on the spatial dimensions of the body schema. Given that AN patients exhibit distorted body schemas, they can be expected to misperceive such affordances, just as they do within experimental settings. Again, though the content of such experiences— "I couldn't fit into her top", "I can't fit in between those chairs"—doesn't *directly* relate to the size of the body, these false affordance judgments do provide an awareness of false information about body size: that it *isn't thin enough* to engage in certain environment focused actions (Gadsby, 2017b, p. 607). This is another form of oversized experience suggested to ground the relevant body size beliefs.

3. Manipulating body representations

If indeed distortion of the perceptual body image and body schema is a relevant factor in the maintenance of AN, we ought to evaluate whether manipulation of this content is possible. We can distinguish two broader goals in which the process of manipulation would be useful. The first relates to the epistemic goal of understanding more about how body representations function and break down in the case of AN. In terms of this broader goal, manipulation is invaluable. Indeed, manipulation is integral to science in general: by manipulating objects under tightly controlled settings, we gain insight into the principles by which those objects operate—the same goes for cognitive structures.

Apart from this broader epistemic goal, there is a more practical advantage to understanding how to manipulate body representations, one which I will focus on here: treatment. As discussed, the empiricist account of AN claims that distorted body representations play a role in the maintenance of AN—through causing the oversized experiences which ground false body size beliefs. As such, manipulating that content in order to reduce distortion would relieve patients of their oversized experiences and, in turn, allow them to positively amend their beliefs about their own body size.

605-606). Within the empiricist literature, this is what's referred to as an *explanationist* account, whereby delusions arise as an attempt to *explain* anomalous experience. These contrast against *endorsement* accounts, where the content of an anomalous experience is simply endorsed as belief (Bayne & Pacherie, 2004).

3.1 The rubber hand illusion

One field of research with a long-standing association with the manipulation of body representation content involves *body ownership illusions* (BOI). Most of the BOI paradigms currently in use can be regarded as some variation of the rubber hand illusion (RHI). In the classic RHI setup, participants sit with an arm resting on a table in front of them, hidden from view, while on the same table sits a realistic life-sized rubber hand (Botvinick & Cohen, 1998). In the *synchronous* condition of this experiment, the experimenter strokes both the rubber hand and the subject's hand simultaneously with two matching paintbrushes, so that the subject sees the rubber hand being stroked *at the same time* as they feel their own hand being stroked. Under this synchronous stroking condition, participants generally begin to feel a sense of embodiment over the rubber hand—they feel as if it belongs to them, or is a part of their body (Longo et al., 2008).

Body ownership illusions have long been associated with body representations in one way or another (Carruthers, 2008; Tsakiris, 2010). Most prominent is the claim that the illusion involves some process of *incorporation*, whereby the content of an internal representation is manipulated so as to incorporate the content of the rubber hand (de Preester & Tsakiris, 2009). Given this incorporation claim, the RHI seems like a promising technique for spatial content manipulation. Of particular relevance are full body variants of the illusion—specifically, experiments which use virtual reality to incorporate the content of a *different sized body* into a subject's body representation(s) (Keizer, van Elburg, Helms, & Dijkerman, 2016; Kilteni, Normand, Sanchez-Vives, & Slater, 2012; Normand, Giannopoulos, Spanlang, & Slater, 2011; Piryankova et al., 2014; Preston & Newport, 2012; van der Hoort, Guterstam, & Ehrsson, 2011).

Yet there is an issue with relying on the proposed notion of incorporation. Researchers have yet to offer a specific functional definition of what this process involves. Further, there is little agreement between researchers about which specific representations are the target of this process (Carruthers, 2009; de Vignemont, 2007, 2017; Llobera, Sanchez-Vives, & Slater, 2013; Longo, Schüür, Kammers, Tsakiris, & Haggard, 2009; Tsakiris, 2010). Given this, a common stance has emerged whereby RHI researchers remain agnostic in regards to which *particular* representations are the target of their experiments (Keizer et al., 2013; Kilteni et al., 2012; Normand et al., 2011; Piryankova et al., 2014).

This trend is understandable. There is a great deal of ambiguity and disagreement surrounding models of body representations, and BOI research is sufficiently complex without having the two problem areas intertwine. However, if we want to truly understand and treat distorted body representations in AN, we must move beyond taxonomy neutral claims about the process of incorporation towards a firm understanding of the techniques which manipulate the spatial content of the perceptual body image and body schema. Furthermore, given their disparate function and content, it's likely there are significant differences in the way in which the body image

and schema function—how they update their spatial content and how it can be manipulated. As such, we must understand their functions individually, in order to successfully manipulate the content of each.

That said, this goal is still achievable—the ambiguity surrounding body representation incorporation isn't insuperable. Within research into full body illusions, many researchers use some form of BSE task on participants before and after the illusion. In what follows, I assess the results of the tasks used in some of these experiments, in light of the previous discussion of the behavioural measures used to measure the perceptual body image and body schema (see section 2).

4. Reinterpreting body ownership illusion evidence

Although there are a number of BOI experiments which induce the illusion using different sized bodies, our interest here is only on those which incorporate some form of body size measure. This narrows the list down significantly, as many of these studies focus on subjective measures of illusion strength, rather than body size estimation (Kilteni et al., 2012; Preston & Newport, 2012). However, of the number of experiments which employ measures of body representation, all seem to suggest that manipulation of spatial content is possible (Keizer et al., 2016; Normad et al., 2011; Perera et al., 2017; Perez-Marcos et al., 2018; Piryankova et al., 2014; Serino et al., 2016; 2018). For brevities sake, I will only discuss two of these experiments at length: the first suggests this manipulation technique is successful on AN patients, the second suggests it affects both the perceptual body image *and* body schema.

4.1 Inducing the effect with AN patients

This first experiment specifically targeted AN patients, comparing them to healthy controls in a virtual reality (VR) BOI paradigm (Keizer et al., 2016). Participants were asked to bare their abdomen and put on VR goggles. They looked down to see a virtual body, of average size, being stroked, while either synchronous or asynchronous stroking was admitted to their own abdomens via motion tracked brush. Participants estimated body size before and after the stroking session and also completed a post-session embodiment questionnaire. While the research is framed in terms of manipulating body representations, in line with most recent RHI literature, it remains neutral on which representations are manipulated. However, as mentioned, insight can be gained by investigating the design of the BSE tasks these researchers employed.

In this study, two BSE tasks were adopted, measuring width and circumference respectively:

> Width of the shoulders, abdomen and hips was estimated by placing two
> adhesive markers on the wall representing the left and right side of the body.
> Circumference was estimated using a piece of string that was placed on the
> floor so that it would fit exactly around each body part. Participants were
> explicitly instructed to estimate the width/circumference of their own body

(e.g. "Please place two adhesive markers on the wall so that your hips exactly fit in between the markers, your size estimation should represent how you experience your body size") (p. 4).

The experiment found that both groups showed a change in size estimation after the illusion. The body size estimate tasks used here clearly falls into the category of metric size estimation, measuring both the body image as well as implicit body representations. Although not a direct measure of the perceptual body image (i.e. a depictive body size estimate task), we can still assume that these results are at least partly reflective of a change in perceptual body image content. The possibility that changes in size estimation recorded were *only* indicative of a change in implicit size content is ruled out by other studies showing that a similar VR paradigm alters the spatial content of perceptual body image content, as measured by *depictive* estimation task (see section 4.1.2). So this study's results appear to confirm that the VR paradigm used is effective in shifting the spatial content of the perceptual body image, for both AN patients and neurotypical participants.

Further, results from the study illuminate the relationship between this process of perceptual body image manipulation and the sense of embodiment itself (as measured by questionnaire). These researchers found that although their participants reported more embodiment in the synchronous condition, they did not show larger changes in body size estimation (p. 15). That is, even in the asynchronous condition, where participants reported little to no embodiment, the same degree of change in spatial content was evident. This seems to suggest that the process underlying the sense of embodiment dissociates from the process of updating the perceptual body image's spatial content.

4.1.2 Body image and schema manipulation

Piryankova and colleagues (2014) also aimed to explore the manipulation of body representations using BOI VR paradigms. Neurotypical individuals were immersed in a virtual environment, with congruent 1st person perspective accommodated through head tracking. They were embodied in either an overweight or underweight avatar and were asked to estimate their "experienced" body size before and after a period of tactile simulation, with each participant undergoing two sessions (asynchronous and synchronous).[7]

Similarly to Keizer and colleagues, these researchers remain neutral on which specific body representations are being manipulated but, again, we can gain insight into the question by looking at the behavioural tasks employed. In fact, two tasks were used to measure the size content of body representations: an affordance task and a BSE task.

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[7] The researchers distinguished between three different targets for body estimate tasks: the experienced body, the physical body and the virtual body. Relevant to the current discussion are the results of tasks aimed at measuring the experienced body, which the researchers defined as "the body that the participant feels she has at that moment" (p. 2). I won't delve into the results associated with these other two terms.

This approach is promising—affordance tasks target the body schema, while BSE tasks target the body image, so adopting both puts us in a good position to compare the effect of the same experimental procedure on the two different representations.

The BSE task chosen is a fairly standard full body depictive design: participants were presented with the image of an avatar—whose size they could control with a joystick—and asked to modify it to the size they felt their body to be. Given that this is a depictive task, we can assume that it's purely a measure of the perceptual body image. Similarly, in the affordance-based task, participants were presented with a set of poles and asked to adjust the width "till the aperture was at a size they could pass through without twisting their shoulders or hips" (p. 5).

The experiment found "that the size of the 1st PP virtual body (underweight vs. overweight) significantly biased the participants' affordance and body size estimations of the experienced body" (p. 11), which seems to suggest that the size content of both the body image and schema shifted towards the size of the avatar. Given that we have good reason to believe these tasks are measuring the body image and schema (respectively) we can make inferences regarding each representation's susceptibility to manipulation.

For example, the researchers discovered that "participants experienced a significant change in their experienced body size (only for the underweight) and affordances (for both) *even before any type of visual-tactile stimulation*" (p. 11, my emphasis). In fact, "even though the synchronous visual-tactile stimulation had a significant influence on the participants' self-reports, it did not significantly impact the ratio of the participants' affordance and body size estimations" (p. 11). In coherence with the finding of Keizer and colleagues, it thus seems that updating of the body image and schema dissociates from the experience of embodiment (see also: Perera et al., 2017; Perez-Marcos et al., 2018; Serino et al., 2016).

5. Implications and Future Directions

These two studies seem to suggest that full body illusion paradigms can be used to manipulate the spatial content of both the body image and schema. While this represents a potentially fruitful method of scientific understanding and disorder treatment, there is still much work to be done. In this final section, I contribute to the task ahead by addressing a few of the relevant issues. First, I discuss the potential duration of these changes in spatial content. Next, I discuss the kinds of sensory evidence which must be manipulated in order to enact this change. I finish by discussing some issues related to the clinical efficacy of the treatment method: its relationship to the usual factors which promote resistance to treatment and its overall effectiveness, as suggested by the empiricist approach.

5.1. Change duration

One important consideration in determining whether this method of manipulation will have clinical use is how long the new dimensions remain intact. The discussed empiricist model states that oversized experiences arise throughout the day, during affordance perception and self-other body comparisons in (mostly social) environments. Therefore, in order for the reduction of the spatial content of these representations to negate these oversized experiences, the reduced dimensions must preserve for long periods of time, well after the participants have left the lab.

There is some tentative evidence to suggest that changes in spatial content preserve over extended periods. In the study by Keizer and colleagues (2016), they included a follow-up condition, using the same behavioural measures on a number of the participants almost 3 hours after the illusion was induced. They found that changes in body size estimation held over a number of dimensions, *especially* in their AN group (p. 14).

So it appears that changes in the spatial content of internal representations may persist for some period of time. Whether this change holds for more clinically useful periods (i.e. days) remains to be seen. However, there is some reason to think that it might. Consider that when a neurotypical individual's body representations are manipulated to be smaller than usual, then (post-manipulation) there will be a flow of sensory evidence contradicting this content. We have good reason to think this veridical sensory evidence will be processed appropriately. After all, neurotypical individuals' representations update accordingly with sensory input from their own bodies—when increasing in body size, their representations enlarge; when decreasing in body size, their representations shrink. So this incoming sensory evidence should serve to shift the incorrect spatial content, undoing the changes in size.

However, the case of AN is different. First, the incoming spatial evidence will now bare *greater* similarity to the internal content. Prior to manipulation, patients' representations are *oversized*, but after the illusion this content *reduces*, bringing it closer to their true body size. So, post- illusion, there is in fact *less* mismatch between sensory input and internal content. Furthermore, even though mismatch will still likely be present, we have good reason to think the relationship between incoming input and stored spatial content is (somehow) impaired. After all, this is presumed to be the reason why the distorted content persists—why their body representations do not update to their veridical, thin dimensions (Gadsby, 2017c). As such, it seems *more* likely that changes in size content would endure in the case of AN. This matches with the evidence from Keizer and colleagues, who found that persistence of changes in body size estimation was more pronounced in their AN group.

One final consideration related to the temporal characteristics of the different body representations is the differences between both representations. The body schema is standardly characterised as more *dynamic* than the body image. This difference in dynamics is clear from consideration of their distinct functional roles. While the body image is thought to represent *ourselves*, (i.e. our bodies) the body schema is not body specific; rather, its function is to track and encode action relevant objects, whether

these are body parts or tools (Maravita & Iriki, 2004). Indeed, the ability to incorporate tools is a paradigmatic function of the body schema, a process which includes incorporation of the *spatial content* of the tool (Cardinali et al., 2009).

Given this functional role, the body schema must be significantly more dynamic in its shifting of spatial content than the body image. As we change between different tools throughout the day, the body schema must *keep up*, rapidly adapting to the different dimensions and "snapping back" to the spatial dimensions of the body once tool use is finished (Gadsby, 2017c, p. 23). This requires a representation which is highly reactive in terms of shifting its spatial content. As such, we might expect to see differences in how long changes in body schema content endure.

5.2 Relationship with sensory evidence

While we have accumulated an impressive body of knowledge regarding the relationship between sensory input and embodiment experience, given the evident dissociation between the two processes, this knowledge does not hold for the relationship between sensory input and spatial content manipulation. Yet understanding this relationship is integral if BOIs are to prove useful as a method of guided manipulation. If we hope to one day use this method to treat AN patients' distorted representations, we must have a strong understanding of which sensory input to modify in order to do so.

In order for the illusion to take place, a subject must be exposed to *the right kinds* of sensory input. This input can roughly be described as sensory evidence in favour of the object being part of the participant's body (Blanke, 2012; Kilteni, Maselli, Kording, & Slater, 2015); I will refer to this as *body evidence*. For example, in the synchronous condition of the classic rubber hand illusion the subject is exposed to visuo-tactile signals: visual signals from the rubber hand being stroked are integrated with tactile signals from the real hand being stroked, driving the illusion. Similarly, in full body variants using VR technology, subjects are exposed to visuo-proprioceptive signals from the seen avatar occupying the same space as the felt location of the body. Indeed, this is the advantage of VR variants of the paradigm, they allow for fine-grained manipulation of the different streams of body evidence.

While body evidence can come in many forms, enough of it must be present before the sense of embodiment can be felt over an object. While there is a sophisticated story emerging about which kinds of evidence are sufficient to trigger the experience of embodiment (Kilteni et al., 2015), the problem at hand is to develop an equally sophisticated story regarding the relationship between sensory evidence and manipulation of the spatial content of the perceptual body image and body schema.

Consider the role of synchronous visuo-tactile input. In both the studies discussed, the addition of synchronicity in visuo-tactile input did not appear to affect the degree of incorporation into either the body image or schema, even though it did modulate embodiment experience, as usual. There are a number of possible explanations for this

finding. We might suppose that synchronous visuo-tactile signals play no role in the manipulation of either of these representations' spatial content. However, this does not cohere with the findings of another incorporation study by Normand and colleagues (2011), who conducted a full body illusion over a larger sized virtual avatar and found that overestimation in a body size estimate tasks (suggestive of an increase in the spatial content of the perceptual body image) was higher in their synchronous condition—although differences were admittedly small (p. 8).

An alternative explanation which accounts for both these strands of evidence is that the evidence participants were exposed to in the two studies discussed was so effective at shifting spatial content that the effect of additional synchronous visuo-tactile input was rendered negligible; so much so that it didn't exert any observable additional effect. Nevertheless, it's still too early to take a firm stance regarding what the case may be—carefully designed empirical studies aimed at uncovering the relationship between sensory evidence and body representation manipulation are needed.

It's also well known that different subjects have different levels of susceptibility to the illusion itself—indeed, some don't experience the illusion at all. It seems likely then that different subjects will exhibit different patterns of susceptibility in the spatial malleability of both their representations.[8] Similarly, different subjects will likely exhibit different patterns of sensitivity towards different modes of evidence. For example, one subject's body image's spatial dimensions might be more susceptible to congruent visuo-tactile signals, another's might be more susceptible to visuo-proprioceptive signals. This point is of significant clinical importance: individual differences must be understood so that the process of spatial content manipulation can be tailored to the specific individuals in need of treatment.

Finally, as in the case of differences in dynamics, there are likely differences in the susceptibility of the body image and schema to different streams of evidence. Again, this much is clear from considering the example of tool use. With only a small amount of use, the spatial content of the body schema shifts, in order to incorporate the tool. Given that the body image does not incorporate tools that are used, different patterns of sensory evidence are clearly required. So, again, the task at hand is to investigate what kinds of sensory evidence (and in what amounts) work best for each representation.

5.3 Treatment resistance

What would a treatment method that employed this manipulation technique consist of? In terms of modifying the content of the patients' body representations, the only important feature is that it exposes them to significant amounts of body evidence,

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[8] For example, it's been shown that age partly determines representation malleability (Serino et al., 2018)

prompting the representations to update. Given this, the tasks might simply involve moving through and interacting with virtual environments over long periods of time.

What's unique about this as a VR is treatment method is that the technology isn't simply being used as an aid for cognitive behavioural therapy (CBT) (e.g. Marco et al., 2013). As such, the success of this treatment method is not tied to patients' receptiveness to CBT. The only important factor here is the updating mechanisms of the perceptual body image and body schema, and their specific susceptibility to body evidence. Indeed, unlike, for example, recent VR treatment methods targeted at reducing phobias (Garcia-Palacios et al., 2002), it's not particularly important what kind of task participants engage in during the VR treatment. The updating of the spatial content of the perceptual body image and body schema is not a process that the patients are even aware of.

This also presents unique advantages over traditional treatment methods in terms of patients' openness and responsiveness treatment. For example, many of the attitudinal factors that are generally thought to contribute to treatment resistance—e.g. denial of illness, emotion avoidance, etc. (Abbate-Daga et al., 2013)—seem unlikely to reduce the effectiveness of the proposed treatment.[9] Indeed, it seems likely that the proposed treatment method would be more appealing than traditional treatment methods for most patients. After all, treatment methods are often highly unpleasant, forcing patients to confront their anxieties or engage in behaviours (i.e. eating) they disdain. Yet the proposed treatment doesn't require any of these elements, it simply requires engagement with a virtual scenario in which one's body is thin. Given that this virtual scenario represents the state of affairs that patients profess to desire (i.e. having a "thin" or "normal" sized body), it seems likely they would be open to such an experience.[10]

5.4 Cognitive biases and body dissatisfaction

While the proposed treatment method may be advantageous for the aforementioned reasons, it's worth more carefully discussing its potential efficacy as a *general* treatment method for the disorder. One emerging theme from the large body of research into AN is that there are likely a significant number of factors which contribute to the disorder's onset and maintenance. Given this, and given that the proposed method only targets one single factor (distorted body representations), one might question its effectiveness as a general treatment method.[11]

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[9] This isn't to definitively claim that they won't have an effect. However, there is no currently known explanation for how such traits could affect the sensory mechanisms tasked with updating the spatial content of the perceptual body image and body schema.

[10] Indeed, during the VR experiment conducted on AN patients, many of them appeared pleasantly surprised by the experience, making statements such as "oh wow, I am so skinny now, this is cool!" (Anouk Keizer, personal communication; also see: Keizer et al., 2016, p. 16).

[11] Thanks to an anonymous reviewer for pushing me to address this point.

In assessing the potential effectiveness of body representation manipulation, it's worth first clarifying some different categories of disorder relevant factors. It's uncontroversial to assume that *body dissatisfaction* drives harmful dieting behaviour: a basic tenet of folk psychology is that dissatisfaction with a changeable state of affairs will drive behaviour which enacts that change. So assuming that a primary goal of treatment is to change the harmful weight loss behaviour, targeting body dissatisfaction is a good starting point. However, in the case of AN, there are other disorder relevant factors to consider. For example, abnormality in the dopamine-mediated reward system may directly drive patients towards dieting behaviour, as such behaviours are conditioned as more rewarding (Sodersten et al., 2016). Obviously factors such as aberrant reward system function will not be affected by the proposed method, so in order to adequately reduce harmful dieting behaviour multiple factors may need addressing.

That said, treating the distorted body representations themselves should be effective as a treatment for body size dissatisfaction, at least according to the empiricist approach outlined. Body dissatisfaction can be thought of as emerging from two main elements: *belief* about one's bodily dimensions and *desire* to obtain some particular bodily dimensions. A common misconception is that body dissatisfaction in AN arises exclusively due to extreme desires i.e. patients place an immense importance on reaching an unattainable ideal size. However, this characterisation of what drives body dissatisfaction does not cohere with the available evidence. Upon asking participants to identify their ideal body size on a range of silhouettes, one recent study concluded that AN patients don't in fact aspire to excessive thinness. Indeed, they found that if the patients in their study were made aware of their true body size, they would seek to *gain weight* in order to reach their ideal size (Moscone et al., 2017). This suggests that body dissatisfaction may not be *exclusively* driven by extreme ideal standards or even drive for thinness (though these factors may certainly still play a role), but rather a lack of awareness of one's true size; in other words, body dissatisfaction may primarily be driven by *false belief* about one's own bodily dimensions. This is the starting point for the empiricist approach, understanding how such false belief could arise.

As discussed, the proposed model claims that oversized experiences are what serve as the proximal cause of such false beliefs, impeding patients' awareness of the true dimensions of their own body size. Adjusting the underlying cause of these oversized experiences (distorted body representations) would thus enable patients to realise that they had already surpassed their ideal standards for thinness, increasing satisfaction with their own body size. Therefore, according to the empiricist approach, focusing on distorted body representations should be more effective at treating body dissatisfaction than addressing drive for thinness, or body size ideals alone.

Nevertheless, within AN research there are a number of further factors—attentional, behavioural and attitudinal—which are assumed to contribute to body dissatisfaction. For example, the phenomenon of *body checking*, whereby patients frequently check disliked body parts and *body avoidance*, whereby patients actively disconfirmatory

evidence (e.g. full body mirror exposure) (Fairburn et al. 1998); *attentional* biases shown in eye gaze studies, whereby patients gaze more often and for longer periods of time at disliked body parts; and *interpretational* biases, whereby patients interpret ambiguous information (e.g. someone commenting "you look healthy") as confirmation of their beliefs about being over-weight (for comprehensive review, see: Williamson et al., 2004). It's widely assumed that these cognitive-behavioural factors bear strong clinical relevance; as such, it's worth discussing their relationship to the proposed method of treatment.

In fact, a recent paper explains how many of these factors fit into the empiricist picture (Gadsby, 2018b). A well-known issue within empiricist research into delusions is *the maintenance problem*, which involves answering why, in the face of contradictory evidence, patients hold on to their false beliefs (Davies et al., 2001). We can appreciate the force of this problem for the empiricist account of AN by considering the particular evidential situation these patients must face. Although patients experience their bodies as larger than reality (in virtue of undergoing oversized experiences) they are also exposed to a significant amount of evidence suggesting that their bodies are in fact thin. This evidence comes in a number of varieties, for example: weight scale and clothes size readings, as well as testimonial evidence from family, friends and clinicians attempting to convince them of their true size.

Answering why patients maintain their false body size beliefs in the face of this contradictory evidence is where these cognitive-behavioural factors become relevant. Such biases often pertain to the way in which patients treat evidence related to their own body size. According to the proposed empiricist approach, these biases in evidence treatment work *in conjunction* with the aforementioned oversized experiences (Gadsby, 2018b). They enable evidence from oversized experiences to play a stronger epistemic role, as patients seek out, attend to and positively interpret such experiences, while evidence from veridical body size experience is avoided, ignored and explained away.

The specific role these cognitive biases within this account is important. It is only in virtue of the underlying oversized experience that these biases are able to exert such a deleterious epistemic effect. That is, without consistent oversized experiences which can be sought out, attended to and positively interpreted, the aforementioned biases would lose their belief reinforcing strength. In contrast to standard cognitive-behavioural models of AN, the empiricist approach suggests treating the distorted body representations which drive oversized experiences would thus be more effective than simply targeting these biases.

One final factor I have not discussed pertains to another kind of oversized experience posited by the empiricist account: *recurrent spontaneous mental imagery*. It's suggested that, during periods of high anxiety, AN (and other eating disordered) patients experience episodes of spontaneous mental imagery, representing themselves as overweight (Cooper et al. 1998; Somerville and Cooper 2007; Somerville et al.

2007). Though not arising from body image or body schema distortion, these episodes of recurrent mental imagery have been suggested as another form of oversized experience (Gadsby, 2017a). That said, research into these episodes is still scarce and their existence and cause need further investigation. Depending on their prevalence, they may also require direct clinical intervention in order to achieve a fully comprehensive treatment for body dissatisfaction.

6. Conclusion

Despite much work remaining, the use of BOI paradigms to manipulate body representations looks to be an auspicious pathway to further understanding and potentially treating the false body size beliefs of AN patients. That said, if researchers wish to further understand this ability, attention must be paid to the theoretical underpinnings of the experiments. Experiments must be designed which aim to manipulate the content of both the perceptual body image *and* body schema, keeping in mind the relevant considerations in designing behavioural tasks to measure these representations. Through careful experimental design, we may move past taxonomy neutral claims regarding incorporation into "internal body representations" and come to understand the *representation specific* effects that exposure to certain forms of body evidence have. Similarly, we may begin the task of understanding the distinct temporal dynamics of changes in the spatial content of these two representations.

As a final cautionary note, we must keep in mind the unique characteristics of individual patients' conditions. As research builds, it's becoming increasingly evident that AN is a causally heterogeneous disorder—different patients' symptoms arise from different factors (Stinson, 2017). As such, treatments that hold for some will not necessarily hold for others. Similarly, as discussed, there are many more issues associated with the disorder than simply the holding of false beliefs about body size— problems which ought to be targeted with their own treatment methods. So even if manipulation of the perceptual body image and body schema content is adopted as a method for treatment, it must be used in conjunction with a number of other techniques tailored to the idiosyncrasies of individual patients.

Finally, though I have suggested that manipulating the content of body representations might be more effective than targeting other factors, treatment methods which target multiple causally relevant factors will always be more effective than those which only target one. As such, the preceding proposal should not be taken as an argument *against* any current treatment methods: manipulating body representations with virtual reality should be seen as an *addition to*, rather than a *replacement of* current approaches.

Acknowledgments

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