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Distorted Body Representations in Anorexia Nervosa

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Abstract:

In this paper, I discuss empirical evidence regarding anorexic patients' distorted body representations. I fit this evidence into a broader framework for understanding how the spatial content of the body is tracked and represented. This framework is motivated by O'Shaughnessy's (1980) long-term body image hypothesis.

This hypothesis posits a representation that tracks changes in the spatial content of the body and supplies this content to other body representations. I argue that a similar kind of body representation might exist and, in the case of anorexia, be distorted. Finally, I suggest that this body representation might become distorted through influence by affect.

Keywords:

Body Representation; Long-Term Body Image; Tactile Form; Body Schema; Anorexia Nervosa

Highlights:

- Evidence of distorted body representations in anorexia nervosa patients is reviewed
- A new framework for how spatial content on the body is represented is proposed whereby a long-term body representation tracks spatial content and supplies it to more dynamic, short-term representations
- It is suggested that anorexic patients' long term body representations become distorted through influence by affect

1. Introduction

Body representations can be defined (minimally) as internal cognitive structures that “function to track the state of the body and encode it, that can misrepresent it and that can be decoupled from it” (de Vignemont, 2016). Body representations are integral to many of our cognitive abilities. In order to perform different cognitive tasks, our brains must represent features of our bodies. In order to mentally picture what our body looks like, we rely on a representation of it in the form of a mental image. In order to reach towards and flick on a light switch, our brain relies on a representation of how long our arm is (de Vignemont, 2010, p. 672). In order to localise where a sound is coming from, our brain relies on a representation of the distance between our two ears and the shape of the pinna (the visible part of the ear) (Aslin, Pisoni, & Jusczyk, 1983; Clifton et al., 1988).

Representations of our bodies can determine how our bodies *feel* to us, how we *experience* them. Because of this, disorders in the way people experience their bodies allow us to better understand how the brain represents the body (Schilder, 1935). For example, in phantom limb disorder, patients feel the presence of a limb that has been amputated. Although they know they no longer have the limb, they can't help but *feel* as if it's still there. This experience can be explained with the hypothesis that their brain is still, somehow, representing the missing limb (Hilti & Brugger, 2010). Another example is xenomelia, whereby a limb is said to be *missing* from a patient's body representation (Brang et al., 2008). This causes the patient to have an extreme desire to amputate the limb.

It's been known for some time that anorexia nervosa (AN) patients also have a disturbed experience of their own bodies, specifically their body's *size* or *shape* (DSM-III-R). Many claim that this distorted experience arises as a result of distorted body representations (Keizer et al., 2013; 2014; Spitoni et al., 2015). In this paper, I review the evidence on distorted body representations in AN. This evidence shows that patients exhibit distortions in three different kinds of body representations: the *body percept* (the mental image we have of our bodies), the *body schema* (used for motor control and simulation) and a representation I call the *tactile form* (used for certain kinds of tactile perception).

I then introduce a representational framework for understanding how spatial content on the body is stored and updated. This framework is based on work by O'Shaughnessy (1980), who claimed a representation (the 'long-term body image') tracks changes in the spatial content of the body and supplies this content to other body representations. I argue that a similar kind of body representation might exist, supplying spatial content to the body percept, body schema and tactile form. I then explain the evidence of distortion in patients' body representations by suggesting it *arises* in their long-term body representations. Finally, I suggest distortion of this representation might occur through influence by affect.

2. Distorted Body Representations

2.1. The Body Percept

The first kind of distortion I will discuss affects one aspect of what is referred to as *the body image*. Gallagher and Cole write, “the body image consists of a complex set of intentional states—perceptions, mental representations, beliefs, and attitudes—in which the intentional object of such states is one's own body” (1995, p. 371). Following Bruch (1962), AN patients are said to suffer from a *body image disturbance*.

It is generally recognised that there are two different components of the body image that are disturbed in AN: a mental image of the body and a collection of attitudes or feelings towards the body (Skrzypek, Wehmeier & Remschmidt, 2001, p. 216; Cash & Deagle, 1997, p. 108). Although both these components are considered disturbed, the attitudes/feelings component of body image disturbance isn't relevant to the current discussion. As such, I will only discuss the perceptual component of the body image, which I will refer to as *the body percept* (Gallagher, 2005, p. 25).¹ Following Bruch (1973) and Slade & Russell (1973) AN researchers have adopted Schilder's definition of the body percept: “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” (1935, p. 11; Smeets, 1997, p. 79).

Evidence that AN patients exhibit oversized body percepts comes from *body size estimate* (BSE) tasks. These involve a variety of different methods such as modifying distance between light points on a wall to match the width of one's body part, drawing one's body size on a wall or selecting a silhouette that best matches one's body size (Skrzypek, Wehmeier & Remschmidt, 2001; Gardner, 2011). While there has been a good deal of disagreement in the past regarding the reliability of the different BSE methods, meta-analysis of previous studies have concluded that AN patients do overestimate their own body size (Smeets et al., 1997; Smeets, 1997; Cash & Deagle, 1997; Farrell, Lee & Shafran 2005; Gardner & Brown, 2014).

Overestimation in BSE tasks doesn't appear to result from a distortion in perceptual abilities. Patients show no overestimation in evaluation of inanimate objects (Slade & Russell, 1973; Bowden et al., 1989). They also show no difference in size perception when showed photographs of their own and others bodies (Smeets et al. 1999; also see: Gardner & Moncrieff, 1988). Finally, as Smeets and colleagues point out, BSE tasks usually require patients to estimate their size without looking at their body either directly or in a mirror (1999, p. 466).² This suggests the size information informing these tasks is stored (i.e. it comes from the body percept).

2.2. The Body Schema

¹ Gallagher uses the term ‘body percept’ to refer to a broad category of perceptual experiences of the body. Instead I am using this term as a shortened version for what AN researchers call ‘the perceptual component of the body image’. This refers to a specific body representation, rather than a group of kinds of experiences.

² However, see section 7.2.

The definition of the body schema varies greatly between different research areas.³ A good starting point is to look at the definition used in the AN literature. This definition is “an unconscious, sensorimotor, representation of the body that is invoked in action” (Keizer et al., 2013, p.1). However, the body schema isn’t *only* unconscious or *only* invoked in action. It is also used for offline motor *simulation*, including conscious motor simulation (motor imagery) (de Vignemont, 2010, p. 673).

We can understand the nature of this representation by considering an earlier definition given by de Vignemont: “a dynamic sensori-motor representation based on the continuous flow of somesthetic and visual information”, necessary because, “if you want to move, you indeed need to know very quickly the position of your limbs at every movement” (2004, p. 145). This quote presents the idea of a consistently updated representation of the body, bearing content relating to its size, shape and current postural configuration. For now, this is the characterization of the body schema that I will adopt.

As in the case of the body percept, it has been shown that AN patients exhibit oversized body schemas (Guardia et al., 2010; 2012; Keizer et al., 2013; Metral et al., 2014). It’s known that when passing through apertures, healthy controls all turn their shoulders at a similar shoulder to aperture width ratio; what’s known as *the critical point* (Warren, 1984; Warren & Wang, 1987). However, recent experiments have shown that AN patients start to turn their shoulders at a higher critical point than controls (Keizer et al., 2013; Metral et al., 2014).

This bias is also found in conditions where patients mentally simulate themselves walking through an aperture (Guardia et al., 2010; 2012; Metral et al., 2014). When asked to picture themselves walking face forward through an aperture and answer whether it would be possible, patients consistently underestimate the aperture width they could fit through. The bias is not present when patients are asked to picture an experimenter walking through an aperture (Guardia et al., 2012).

This evidence suggests that AN patients’ body schemas represent their bodies as larger than reality. Because the body schema is used for both motor control and motor simulation, this changes the way they move around environments and how they judge their ability to do so. So not only do AN patients have a body image disturbance, they also appear to have a body schema disturbance: both representations are oversized.

2.3. The Tactile Form

2.3.1. Introducing the Tactile Form

³ The term body schema is used interchangeably to refer to a particular sensori-motor representation, a group of kinds of representations, a cognitive system used for motor control that may or may not make use of representations and a kind of pre-reflective bodily awareness (see: Gallagher, 2005; 2008; Gallagher & Zahavi, 2008, p. 146; de Vignemont, 2010).

Apart from evidence that AN patients exhibit oversized body percepts and body schemas, they also appear to have an oversized representation of the body used for tactile processing, what Medina and Coslett (2009) call a 'body form representation'. To emphasise its specific cognitive role and distinguish it from other body representations, I will refer to this representation as *the tactile form*. In order to explain what function the tactile form plays, I'll briefly discuss how touch perception functions.

When the body surface is touched, afferent signals are transmitted from mechanoreceptors on the skin to the somatosensory cortex. The primary somatosensory cortex of each hemisphere contains a topographically organised representation of the contralateral side of the body. This somatotopic representation is inverted, with legs represented medially and face and hands laterally. The size of representations of skin regions depends on the density of mechanoreceptors on that portion of the skin, which in turn determines spatial tactile acuity for that area (Penfield and Boldrey, 1937). For example, skin regions such as the fingers have large representations in the somatotopic map while the back and torso have small representations. As such, tactile spatial acuity is twenty times greater on the finger than the back (Serino & Haggard, 2010, p. 225).

We can now introduce what Spitoni and colleagues (2010) refer to as a *primary* property of touch. An example of this kind of property is pressure. For example, de Lafuente and Romo (2005) showed (on monkeys) that pressure from tactile stimuli on the skin can be directly read off the firing of neurons in the somatosensory cortex. As such, the physiological resources needed for the coding of pressure are supplied by the somatosensory system, making pressure a primary tactile property (Spitoni et al. 2010, p. 185).

Secondary properties of touch cannot be processed at the same first level of somatosensory processing. An example of this is perception of tactile distance on the skin. It is claimed that tactile distances are measured by first localising points of contact on the body. Localising points of tactile input on the body surface (topognosis) is said to require mapping onto a body representation distinct from the somatotopic cortical map (Dijkerman & de Haan, 2007; Longo, Azanon & Haggard, 2009; Medina & Coslett, 2009; Spitoni et al. 2010; Serino & Haggard, 2010). Only after the points are localised onto a body representation can the distance between them be estimated. Taylor-Clarke, Jacobsen & Haggard write:

judging tactile distance requires a rescaling of neural signals, from a distorted, primary [somatotopic] representation based on receptor density, to an object-centred space. This rescaling requires a representation of the physical size of the simulated body part. (2004, p. 219)

This 'distortion' of the somatotopic map does carry over somewhat to the perception of tactile distances, as shown by the Weber illusion. Weber (1834/1996) showed that the perceived distance between two tactile points is larger when presented on a region of high tactile acuity. However, Taylor-Clarke,

Jacobsen & Haggard (2004) estimate that the magnitude of this illusion is only 10% of what it would be if we relied on the somatotopic map alone. The distortions of the primary somatotopic map must be corrected by a second process, which maps them to a more realistically scaled body representation (Longo, Azanon & Haggard, 2009, p. 659). This more realistically scaled body representation is what I refer to as *the tactile form*.

The tactile form has its roots in Head and Holme's (1911) original body representation taxonomy. Their model involved a three-way distinction between postural schema (body schema), body image and a body representation called the superficial schema—specifically responsible for localisation of tactile stimulation. However, the superficial schema isn't often spoken of and there is some confusion in current body representation literature over which body representations are used for localisation of tactile input.⁴ Despite this confusion, there is a wealth of evidence supporting the existence of the tactile form and dissociating it from other known body representations

Before distinguishing the tactile form from the other two (more well-known) representations I have been discussing (body percept and body schema), I will address an issue in the literature on body representations and tactile processing. I have claimed that tactile distance estimation (TDE) (sometimes referred to as 'tactile size perception') involves a first step that localises the tactile input to a more accurate body representation, the tactile form. However, there is an objection to this view of how TDE cognitively functions. It is sometimes hinted that different representations are used for tactile localisation and TDE (e.g. Mancini et al., 2010, p. 1200; Longo, 2015, p. 9). If this is the case, then a different cognitive story needs to be offered for how TDE functions and what relationship it has to tactile localisation.

One thing that might motivate a distinction between representations used for localisation and distance estimation is differences in the apparent distortion of these representations. While there has been a wealth of research into errors in TDE (suggestive of a distorted representation), less has been discovered using tactile localisation tasks in healthy subjects. In the experiments where consistent tactile localisation errors have been found, it's not clear how these error patterns match up with those from TDE tasks (e.g. Mancini et al., 2011).

However, it must be remembered that tactile localisation tasks actually involve two localisation steps. After a point is localised on the tactile form, participants must demonstrate this to the experimenter, generally by pointing out the location on an accurate pictorial representation of the body.⁵ This second step could account for the heightened accuracy in localisation, as opposed to distance estimation. Picture a situation where the tactile form represents the hand in a

⁴ There is also confusion about what the term superficial schema ever referred to. It is sometimes claimed that this was the original name for the body schema and other times it's claimed that the superficial schema is now referred to as the body image (e.g. Cardinali et al., 2011).

⁵ For example, Mancini and colleagues (2011) used a life-size silhouette outline based on a photograph of the participant's hand. Steenbergen and colleagues (2012) used an actual photograph of the participant's arm, shown on a computer monitor.

distorted manner but the picture used to indicate the points is accurate (see fig. 1 below).

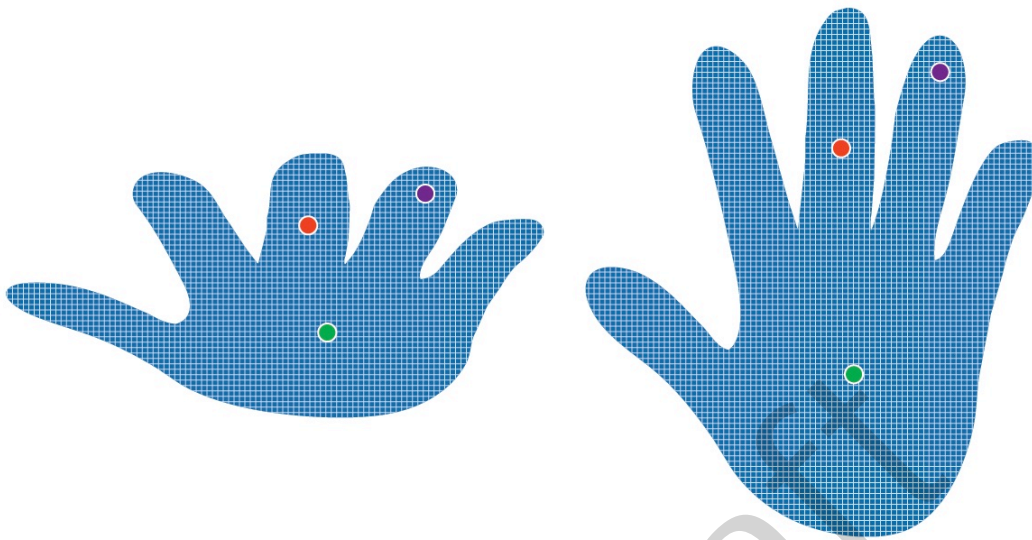


Figure 1: Points on a distorted representation of the hand's surface are remapped onto an accurate representation.

When mapping points from the distorted representation to the accurate representation many of the errors in localisation could be corrected.⁶ TDE tasks do not undergo any second step of referencing points to a different representation. After localisation, the distance between the two points is directly estimated and indicated. This fact could account for the qualitative difference in errors between each of these kinds of tasks.

While there has been a wealth of research establishing a dissociation between body schema and body percept, dissociating the tactile form has largely been overlooked (de Vignemont, 2010). One relevant body of research comes from Longo & Haggard, who showed dissociations between body percept, body schema and tactile form by investigating how each represents the back surface of the hand (for review, see: Longo, 2015). Although both the tactile form and body schema represent the back of the hand in a distorted manner, these spatial distortions are quite different (Longo & Haggard, 2010; 2011). Using a BSE task, they also discovered that participant's body percepts represent their hands quite accurately, in comparison to the body schema and tactile form (Longo & Haggard, 2010). As such we can distinguish between the body percept, body schema and tactile form.⁷

⁶ It might also be this second step that introduces the patterns of localisation errors that have been discovered.

⁷ There is evidence to suggest that *immediate* mapping of tactile input onto the body's surface in external space (i.e. the body schema), without conscious detection of the input is possible. This is shown in cases of numbness, where patients can physically point to tactile targets that they cannot consciously detect. In this case, an intermediate step (mapping the tactile input from the somatosensory cortex to the tactile form) might not be necessary. However, the kinds of touch perception tasks AN patients show differences in all require conscious perception. Therefore, I won't discuss this unconscious touch-processing route (see: Dijkerman & De Haan, 2007).

However, the tactile form does appear to have *some* connection with the body schema and body percept. Take the example of tool use. Tool use is generally regarded as involving the incorporation of the tool into the body schema (de Vignemont & Farnè, 2010). However, this incorporation has an effect on tactile localisation also. Not only do we localise tactile input onto tools that we use, this localisation follows the same principles as localisation of tactile input on hands (Yamamoto and Kitazawa, 2001). Changes in localisation of touch even remain for some time after tool use (Cardinali et al., 2009). Likewise it has been shown that particular illusions caused by aberrant proprioceptive input can cause alterations of both the body percept and tactile form (de Vignemont, Ehrsson & Haggard, 2005). This ambiguity surrounding the relationship between tactile perception and the body schema/percept likely contributes to the uncertainty regarding tactile perception and body representation.

2.3.2. Anorexia Nervosa and Tactile Form Distortion

Turning to the AN literature on tactile perception, Keizer and colleagues (2011) showed that patients significantly overestimate tactile distances compared to controls. This seems to suggest that AN patients not only have an enlarged body percept and body schema but also an enlarged tactile form. In a follow up study, the results were replicated and, additionally, it was found that patients' tactile distance overestimation was more profound for the abdomen area (Keizer et al., 2012). This suggests that AN patients, rather than having a *generally* oversized tactile form, might exhibit a specifically distorted representation that coheres with cultural ideas about how overweight bodies look (i.e. wider abdomens) (p. 535).

The specific nature of AN patients' tactile form distortions was further explored by Spitoni and colleagues (2015). They ran TDE tasks on the thigh, abdomen and sternum of AN patients, replicating the results of overestimation in tactile distance but only for the thigh and abdomen, not for the sternum. Furthermore, they compared horizontal and vertical TDE tasks and discovered that tactile distance overestimation only occurred along the horizontal axis. This is further evidence that rather than having a generally oversized tactile form, AN patients exhibit a specifically distorted body representation, one that coheres with the particular dimensions of an overweight body: wider, specifically in areas that are known to put on weight (thighs and abdomen).

The specific dimensions of this tactile form distortion also generally cohere with distortion seen in patients' body percepts. Using a BSE task, Spitoni and colleagues measured patients' body percepts, discovering that (like the tactile form) they were wider, specifically around the abdomen, rather than simply being larger *in general* (p. 187). This work lines up with previous findings in BSE experiments (Slade & Russell, 1973; Molinari, 1995).

3. O'Shaughnessy's Long-Term Body Image Hypothesis

I will now introduce O'Shaughnessy's 'long-term body image' hypothesis (1980, 1998). O'Shaughnessy claimed the long-term body image is a representation that contains spatial information about one's body. This spatial information is combined with postural sensation (e.g. proprioception) to generate short-term body images (1998, p. 187). O'Shaughnessy's justification for positing this long-term body image is that all short-term body images share a common spatial content and "while the content of proprioception is spatial and while postural (etc.) sensations cause proprioception, postural sensations cannot be *the original bearer* of spatial content in proprioception" (p. 195).⁸

This is because proprioception and the somatosensory system in general are not capable of independently supplying spatial content regarding the body. The somatosensory system relies on a range of different receptors that provide information about limb position, movement, tension, force, effort, and sense of balance. These receptors have evolved to supply afferent signals with very specific content. For example, muscle spindles monitor muscle stretch, golgi tendon organs monitor tendon tension and joint receptors monitor joint position (de Vignemont, 2014a, p. 990). However, no specific receptors exist to supply size and shape information regarding the body (Proske & Gandevia, 2012; de Vignemont, 2014a, p. 991).

While we probably rely on vision the most to gain information about our body size, it's clear that we don't have consistent visual access to the spatial content of the body. Due to head position, the body is rarely in the visual field. Furthermore, if we relied on a constant stream of visual perception to supply spatial information regarding the body then movement, tactile localisation and mental perception of one's own body with the eyes closed would be impossible. Given that there is no constant sensory input delivering the spatial dimensions of the body, processes that rely on this information are what Clark and Toribio (1994) call 'representationally hungry'. Body size content cannot be reliably plucked from the sensory systems, so this information must be stored internally.

O'Shaughnessy's solution to this problem was to claim that the spatial content of proprioceptive experience originates from a body representation called the long-term body image (LTB). The LTB determines how we experience the spatial properties of our body. So much so that were we to flex our arm while having a LTB that isn't human (e.g. one that represents an octopus), "then despite having a human shape and despite the presence of posture-caused phenomena like sensations of posture, one could not have the experience of seeming to be in the presence of a flexed (very roughly) arm-shaped thing" (p. 184). So, for O'Shaughnessy, experience of the spatiality of our own bodies is representationally mediated, by spatial content derived from the LTB.

O'Shaughnessy writes:

⁸ I won't go into a description of O'Shaughnessy's three different short-term body images, as they aren't relevant to this paper.

The contents of this [representation] tend to change very slowly, generally paralleling changes in actual body size and shape: the image may be presumed to change its dimensions during the time of our life when we are growing, and to change its shape during adolescence or maybe somewhat during pregnancy and very likely over the decade in which we become hugely fat (p. 192).

O'Shaughnessy identifies three origins for the spatial content of the long-term body image: changeless-innate (e.g. fingers), developmental-innate (e.g. growing) and experience acquired (p. 193). Incorporation of experience-acquired spatial content allows for appropriate additions (or subtractions) that could not have been genetically anticipated (e.g. losing an arm or gaining an unexpected hump).

4. Dynamic Body Representations

A wealth of research into body representations has happened since O'Shaughnessy first introduced his distinction between short-term and long-term body images and his model is rarely still talked about. However, I will suggest that a body representation much like O'Shaughnessy's LTB could play a unique role in conjunction with the body percept, body schema and tactile form. To do so, I will first discuss evidence regarding the *spatial plasticity* of these representations. This evidence shows that they are highly *dynamic*, i.e. they can rapidly modify their spatial content according to online sensory input. I will claim that this dynamic nature requires the role of a more *stable* LTB to maintain the default spatial parameters of the body.

4.1. Tool Use and the Body Schema

The most obvious and well-known example of sensory driven modification of the spatial content of a dynamic representation is the case of tool use and the body schema. Consider our ability to use tools:

Humans are proficient tool-users, it would make an obvious phylogenic advantage to have developed a body representation that allows one to immediately "tune" the motor control requirements to the physical and mechanical characteristics of a novel tool. (de Vignemont & Farnè, 2010, p. 14)

With the help of a highly adaptable body schema representation, this is exactly what we can do. It has been shown that tool use incorporates the tool in to the body schema (Berlucchi and Aglioti, 1997; Johnson-Frey, 2003; Maravita & Iriki, 2004; de Vinemont & Farnè, 2010). Importantly, this includes modifying the spatial content of the body schema to include the dimensions of the tool (Cardinali et al., 2009).

However, after use of the tool is finished, the body schema must regain its default parameters. As de Vignemont & Massin put it, "We may think of [the body schema] in terms of plastic band: we can stretch it as much as we want but it

always comes back to its default size” (2015, p. 17). This is where the LTB might come in handy. It might store spatial information offline so that the body schema can shift its spatial content, without losing its veridical parameters. These stored default parameters could allow the schema to ‘snap back’ to its veridical (body-minus-tool) dimensions.⁹ While the body schema is *dynamic*, allowing it to easily stretch its dimensions, the LTB would be more *stable*, only updating its spatial dimensions to match changes in the body’s actual structure.

It might also be that, after tool use, the body schema simply updates itself according to fresh sensory input, constantly re-updating its spatial dimensions to account for the current state of the body. The fact that it returns to its default dimensions doesn’t count as *strong* evidence that these dimensions must be stored elsewhere. However, there are other phenomena that occur during tool use that suggest spatial information on *just* the body might be retained.

Even when tools are incorporated into our body schema, we don’t truly *act* as if they are part of our body. Povinelli, Reaux & Frey write:

tools are frequently used in ways that we would never employ our hands. For instance, we will readily use a stick to stoke the hot embers of a campfire, or stir a pot of boiling soup with a wooden spoon. (2010, p. 243)

They found that chimpanzees also exhibit this behaviour, opting to use a tool to open the container of a box that potentially contained aversive objects. They conclude that chimpanzees must maintain a representation of their hand, separate from the tool incorporated body schema (p. 246). Longo and Serino concur with this conclusion, they write:

effective guidance of the tool may require it being treated as part of the body, even as safety considerations may necessitate it being strongly distinguished from the body. Such conflicting requirements highlight the need for *multiple body representations, maintaining parallel, and potentially inconsistent, representations of the body with or without the tool.* (2012, p. 229, my italics)

As such, there might be an ongoing need for a stable representation that doesn’t update its content but rather maintains the default parameters of the body; a perfect job for the LTB.

Not only might the LTB’s spatial content allow the body schema to snap back to its veridical dimensions after tool use has ended, this stored content could also play an *ongoing* role in tool use. Having two representations, one of the body-plus-tool system (in the body schema) and another of the default parameters of *just* the body (in the LTB) might allow us to easily distinguish between the body and the tool, ensuring we can easily and unconsciously make use of tools for tasks we wouldn’t use our body for.

⁹ This ‘snap-back’ might not be such a sudden occurrence. Cardinali and colleagues (2009) found the kinematic effects resulting from incorporation of a tool into the body schema last up to 10-15 minutes post-tool use.

4.2. The Plasticity of the Body Percept and Tactile Form

There has been a lot of work done exploring the plasticity of the body schema. However, when it comes to the body percept and tactile form, much less is understood. It has been shown that the spatial content of the body percept can be altered as a result of changes in online sensory input. When anesthesia of the thumb and lips is produced (disturbing afferent input from these locations) there is an illusion of increase in size that affects the body percept (as measured by a template matching BSE task) (Gandevia & Phegan, 1999; see also: Paqueron et al., 2003).

There is also evidence that the tactile form can shift according to proprioceptive input. In the Pinocchio illusion a vibrator is applied to the bicep tendon, stimulating a muscle spindle normally stimulated by the stretching of the muscle. If the participant is holding on to their nose at the same time then a sensation of the stretching of the nose can result, “there is a sense of wonder as the dimensions of the body are perceived to change; as one subject reported in test configuration 1A: Oh my gosh, my nose is a foot long! I feel like Pinocchio” (Lackner, 1988, p. 284). De Vignemont, Ehrsson & Haggard (2005) showed that this illusion affects the tactile form by modifying the paradigm so that the illusion affected participant’s index finger (rather than nose). While maintaining vibration, they conducted TDE tasks on the finger, finding a bias in overestimation.¹⁰

As in the case of modification of the spatial content of the body schema, after the aberrant sensory input (or lack thereof) in these tasks subsides, the dynamic representations ‘snap-back’ to their default body dimensions.¹¹ However, it’s not yet clear what functional role the spatial plasticity of the body percept and tactile form plays. Although the specifics of the role that sensory systems play in influencing the spatial content of the dynamic representations isn’t entirely clear, they certainly play some role. As such, I present the following model of how the spatial content of one’s body is represented:

¹⁰ A template matching BSE condition where patients were asked to point to a picture of a finger that best represents the perceived size of their own finger further suggests the body percept was modified.

¹¹ To ensure this ‘snapping back’ is the dynamic representation returning to default parameters supplied by the LTB, rather than them re-updating as a result of new visual input regarding body size, an experiment could be conducted where participants are blindfolded during and after Pinocchio illusion vibrations are administered. If subjects’ tactile forms snap back into default size (as verified by a TDE task) without visual input supplying what this size is, we can presume the ‘snap back’ hypothesis is true.

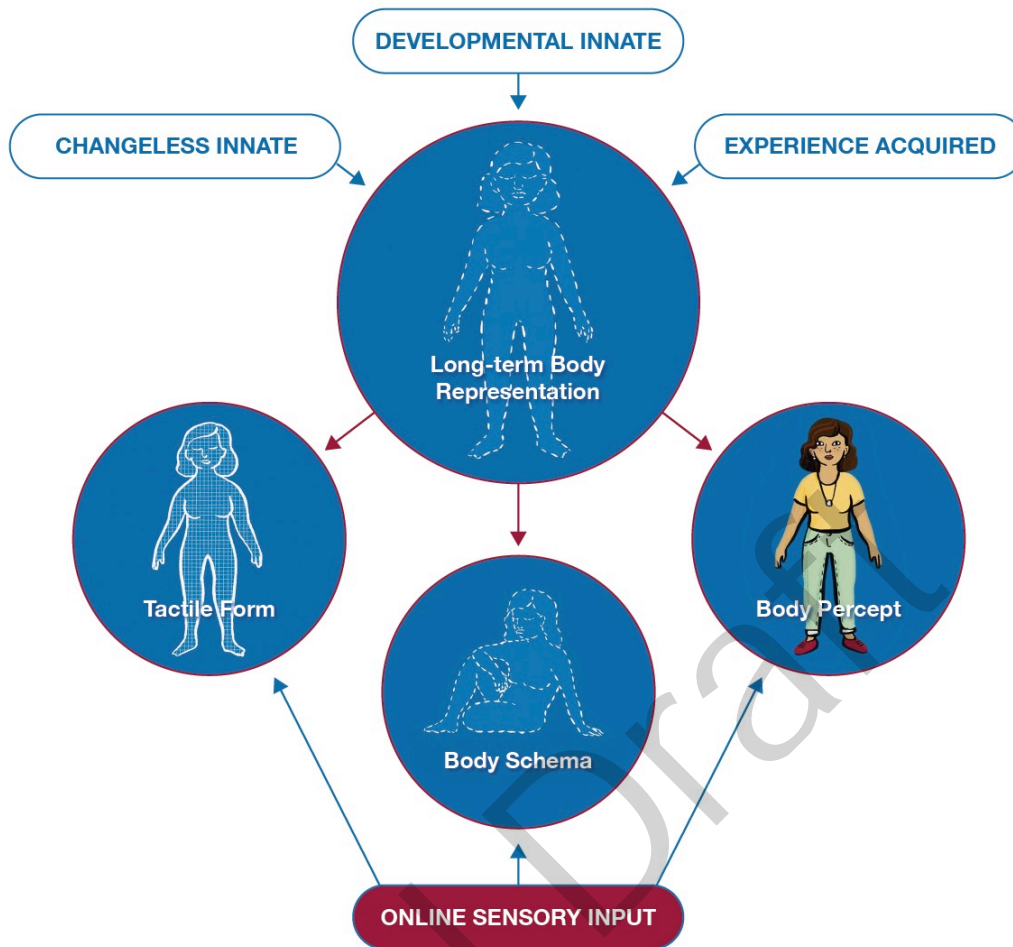


Figure 2: Flow chart of spatial content.

In this model, the LTB¹² tracks the spatial content of the body, using a combination of O’Shaughnessy’s three routes. It then supplies this content (when needed) to the dynamic representations. Each dynamic representation’s spatial content is jointly determined by the LTB and certain online sensory input.

5. Short-Term Body Representations

I have claimed that the body percept, body schema and tactile form can be thought of as *dynamic* representations, which can easily have their spatial content modified according to online sensory input. This dynamic nature makes clear what role a more stable LTB might play. In this section I will go one step further, suggesting that not only are these representations dynamic, they might also be thought of as *short-term*. As we will see, this short-term classification makes the need for an LTB even clearer. Because of the comparative lack of research into the tactile form, I will focus my discussion here on the body percept and body schema.

¹² Although I will retain the abbreviation ‘LTB’, to distinguish it from the concept of a *body image*, this representation will be named the ‘Long-Term Body Representation’.

De Vignemont defines short-term representations as “representations with a very short life-scale. [They are] built up at time t , stored in working memory, and erased at time $t + 1$ by the next one” (2010, p. 672). In contrast to this idea of a short-term representation we can think of a long-term representation as *storing* content.¹³ This content is generally never erased, only *updated*.¹⁴

When reading the literature surrounding the body schema and hearing about how it is *updated* by multi-sensory information and tools are *incorporated* into it, it is natural to think of it as a long-term representation with content that constantly changes but is never erased.¹⁵ However, de Vignemont offers a more nuanced discussion of what the body schema is, particularly in relation to the motor system. In the motor system, there are two kinds of models to consider: *inverse models* that compute the motor commands necessary to achieve the desired physical state (given the current physical state) and *forward (emulator) models* that predict the sensory feedback of these specific motor commands (2010, p. 673; Grush, 2004).

De Vignemont describes the relationship between the body schema and these models like so: the inverse model is “fed by the *initial body schema*, including long-term information like the size of the limbs, and short-term information like the joint angles and the hand position” (2010, p. 673). The forward model anticipates the sensori-motor consequences of the action based on motor commands resulting in *the predicted body schema*. This predicted body schema is used for motor imagery and it also allows anticipatory control of movements. Finally, sensory feedback from an action carrying information about which body parameters have been altered generates *the updated body schema*.

De Vignemont writes, “Consequently, both the predicted body schema and the updated body schema are dynamic short-term body representations, whereas only the initial body schema includes both short-term and long-term body representations” (p. 673). What we are interested in for the sake of this paper is the initial body schema.

De Vignemont is suggesting that the initial body schema is a *collection* of representations, some short-term and some long-term. However, I suggest that we think of the body schema as a single integrated, short-term representation of

¹³ The long-term/short-term distinction bears some similarity to Carruthers’ (2008) distinction between online and offline representations. Offline representations are relatively stable and represent what the body is *usually* like. While online representations represent how the body is currently, are newly constructed (moment by moment) and are directly ‘plugged into’ current perception of the body (p. 1302). However, although the short-term/long-term distinction is similar, it isn’t a perfect match. According to Carruthers, online representations are generated of *any* body we perceive (2013, p. 41). Because the representations I am discussing (body percept, body schema and tactile form) only represent *our* body, they do not classify as online representations (in Carruthers’ sense).

¹⁴ The content might become erased in death or through cognitive malfunction.

¹⁵ Head and Holmes original classification seems to conceptualise the postural (body) schema as a constantly updated long-term representation, e.g. “we are always building up a postural model of ourselves which constantly changes. Every new posture or movement is recorded on this plastic schema” (1911, p. 151)

the current physical state of the body: one that is *generated* according to both short-term information from the sensory systems and long-term spatial dimensions from the LTB.¹⁶

Under this scenario, no initial body schema would exist until required by an inverse model. When we are inactive (e.g. during sleep), there is no body schema representation just waiting to be made use of. Only when we are acting or assessing our ability to act, is information from the proprioceptive system and the LTB integrated to form a representation of the current state of the body, which can then be used to calculate the appropriate motor commands. Much like the predicted and updated body schemas, this single integrated representation would be considered short-term, generated at time t to feed the inverse model but erased at time $t+1$ once it has filled this role.

Throughout the day the generation of body schemas would likely be a constant process as a vast array of motor actions are simulated and carried out. During tool use, the content of these short-term body schemas would include the relevant tool.¹⁷ Multiple body schemas might even be generated simultaneously and fed to multiple pairs of forward/inverse models (Wolpert & Kawato, 1998). These short-term initial body schema representations would also affect other representations 'downstream' (e.g. the predictive body schema).

This idea of dynamically generated short-term representations also fits nicely with the function of the body percept. As Smeets (1997) argues, we must think of the body percept not as the retrieval of an offline representation, as if we were retrieving a picture from a photo-album; rather, it must be thought of as the *construction* of a mental image. This becomes clear when you consider that mental imagery, including imagery of our own bodies, can be constructed however we like. I can readily construct a mental image of a grandmother on roller blades (p.88). Likewise, I can readily construct a mental image of myself on roller blades, wearing the wig of a grandmother.

It wouldn't be correct to say this was a stored image of myself, just waiting to be accessed. Rather, these mental images are constructed from stored information, albeit organized in whichever way we desire (p. 88). Presumably, information about the different elements (what rollerblades look like, for example) is stored somewhere, ready to be accessed if rollerblades are ever to be 'imaged'. Likewise, I claim, size information about the body is stored, in the LTB, ready to be imaged when needed.

Thus the body percept, much like any other mental imagery, is constructed on the fly according to what the mental task requires. For some tasks (such as BSE tasks) a veridical picture of the body is needed, so information about the body (only size information, in this case) is constructed into a mental image as

¹⁶ The integration of multiple kinds of content to form single, unified representations has been discussed before (Carruthers, 2013; de Vignemont, 2014a, p. 1003; 2014b).

¹⁷ A representation of the relevant tool would likely be generated and temporarily stored to aid in the generation of appropriate short-term body schemas in this case (see: Imamizu et al., 2000)

accurately as possible. Other mental imagery tasks require us to use the imagination to alter how our bodies look (e.g. imagining what I would look like with black hair). Just as we can consider the initial body schema as a short-term representation, erased at $t+1$ after its task has been fulfilled, we can also consider these mental images (body percept(s)) as short-term representations.

When we think of the body schema and body percept as short-term representations, a question naturally arises—how do we explain the common content between these representations?¹⁸ As O’Shaughnessy points out, this content can’t reliably be sourced from the sensory systems whenever a short-term representation needs to be generated. This is a problem that can be solved by the existence of an LTB like representation, one which stores spatial content on the body. This spatial content (along with other kinds of content, including from the online sensory systems) can be used to generate short-term representations, explaining how they come to have common content.

It’s important to note that this doesn’t mean different short-term representations can’t also differ in their spatial content. The generation of short-term representations doesn’t mean that stored LTB content is *isomorphically* reproduced. However, under this framework, mismatches in content must be understood as arising during the *generation* of short-term representations, rather than as differences in *stored* content. This is an important point, as it has been shown that the body percept, tactile form and body schema represent the spatial properties of the hand differently (Longo, 2015).

6. Anorexia Nervosa and the LTB

I have suggested that the LTB stores content regarding body size and this content is transferred to (or used to generate) the task-specific dynamic representations. If we accept this model then perhaps distortion of AN patients’ dynamic representations originates in the LTB i.e. distorted content is imported from the LTB into the dynamic representations, causing the patterns of errors found in BSE, TDE and affordance experiments.

I will now explore how this claim fits with evidence from AN research. As discussed, evidence shows that AN patients exhibit distortion in all of their dynamic representations. Furthermore, there have been correlations found between the different representations’ levels of distortion. Case found a within-subject association between body dissatisfaction, body percept distortion and tactile form distortion (2013, p. 124). Her experimental setup (involving showing participants manipulated reflections of their bodies) saw body dissatisfaction and overestimation in BSE and TDE tasks all fluctuate within subjects. This suggests that distortion of the body percept is linked with distortion of the tactile form and both are tied to body dissatisfaction. Although this correlational evidence doesn’t provide *strong* support for the LTB distortion hypothesis, it does sit nicely with the more general idea that the different distortion shares a common cause.

¹⁸ Thanks to reviewer 1 for pointing out the importance of this argument.

Keizer and colleagues (2013) also found evidence suggesting a strong link between distortion of the body schema and body percept in AN patients. Not only did they test patients' body schemas with their aperture-walking paradigm, they also had patients complete a BSE task: drawing a line estimating the distance between their shoulders. As predicted, AN patients overestimated their shoulder width in this task. However, the experimenters made an even more interesting finding. Based on the participants estimated shoulder width and the width of the aperture they started to rotate their shoulders at, they discovered that "if AN patients' shoulders were as wide as they estimated them to be, they would perform equal to [healthy controls] on body-scaled action" (p. 5). So AN patients are, in-fact, moving their bodies with the same dynamics as healthy controls, albeit they are moving *as if* their body schemas had the same shoulder width dimensions as their body percepts.

What this shows is AN patients' body schemas and body percepts have matching spatial content (shoulder width), despite both representations being distorted. This exact dimensional match could be due to the percept and schema having some *direct* causal relationship whereby they share spatial content. However, it might also be that these representations are gaining their spatial information from a single, distorted source. The experimenters make a similar suggestion, they write: "this [evidence] implies stored information on body size is disturbed in AN, which in turn affects perception-related body image as well as action-related body schema representations" (p. 5). This view fits nicely with my proposed model regarding the role of the LTB.¹⁹

7. How does the LTB become Oversized?

If we accept that AN patients' LTBs become oversized, the question remains: how does this come about? I will address three possibilities. The first is that the LTB has failed to update veridically after sudden weight loss. The second is that a perceptual deficit specifically related to perceiving one's own body is to blame. I will argue that the evidence counts against these two hypotheses. Instead, I suggest that affect might play a role in distorting the LTB.

7.1. The Failed Update Hypothesis

One explanation for the oversized dimensions of AN patients' LTBs is that they have failed to update to new, thinner dimensions after sudden weight loss. Similarly, Guardia and colleagues have suggested that a failure to update might explain patients' oversized body schemas (2012, p. 7). Metral and colleagues aimed to test this hypothesis. They "took account of the patients' weight before the onset of AN (as reported by the patients themselves), the weight one month and six months before the experiment and the weight at the date of the

¹⁹ Although this evidence is promising, it should also be noted that, in some cases, researchers have attempted to find correlations between distortions in the different dynamic representations and failed (Keizer et al., 2011, p. 118; 2013, p.4). Given the conflicting evidence, this is an issue that needs further empirical testing (see section 9.1).

experiment” (p. 8). However, they found no significant positive correlation between body weight before the onset of AN and the dimensions of their oversized body schemas (represented by critical point).

Even more damning to this hypothesis is evidence from Keizer and colleagues’ (2013) body schema study. In this experiment one group consisted of participants with EDNOS (eating disorder not otherwise specified). These participants had previously been diagnosed with AN but had regained their normal body size after a period of treatment. This is what classified them as having EDNOS rather than AN, they currently had healthy BMI and body sizes.

This group also showed an increased critical point, one that matched the AN group (p. 6). However, these EDNOS patients’ bodies had returned to their normal sizes. This means they no longer had undersized body dimensions their body schemas could have failed to update to. This rules out the explanation that AN patients have representations (LTB or body schema) that haven’t properly updated to reflect their new, smaller dimensions.

7.2 The Distorted Perception Hypothesis

I have discussed how AN patients don’t have any *general* deficits in their perceptual abilities and how overestimation in BSE experiments results from oversized representations (the body percept). However, some recent BSE experiments have attempted to establish the existence of a certain kind of perceptual deficit by including ‘perceptual’ BSE conditions in their experiments (Shafran & Fairburn, 2002; Øverås et al., 2013).

These conditions involve exposing patients to a mirror, while next to the mirror a photo of themselves is projected. This photo is manipulated so that it is the same height as the mirror reflection of the patients but either wider or narrower. Patients are asked to modify the image’s width until it represents the width of their body *as they perceive it in the mirror*. In both experiments done using a perceptual BSE condition, eating disorder groups overestimate body size in the ‘perceptual’ task, compared to healthy controls.²⁰ Furthermore, Øverås and colleagues (2013) discovered AN patients overestimate body size even more in this perception based task compared to a standard ‘memory based’ BSE task.

One might be tempted to interpret these results as showing that AN patients have a deficit in their perception, albeit one that is restricted to viewing themselves in a mirror. This interpretation sits nicely with patients’ reports that when looking in the mirror they *see* themselves as fat (Smeets & Panhuysen, 1995, p. 109; Espeset et al., 2011). If this were the case, then perhaps faulty self-perception is what updates the LTB to erroneous dimensions.

However, interpreting the results in this way would be falling for what is referred to as the El Greco fallacy (Rock, 1966; Anstis, 2002; Firestone,

²⁰ While Øverås and colleagues’ group was only made up of AN patients, Shafran & Fairburn’s group was a mix of AN, Bulimia Nervosa and EDNOS patients.

2013). El Greco was a Spanish renaissance artist who famously painted subjects with elongated fingers. In the early 1900s it was suggested that El Greco might have been suffering from astigmatism, an ocular defect that distorts the perceived environment by vertically stretching it. However, this theory runs into an important conceptual problem. As Firestone & Scholl explain:

If El Greco truly experienced a stretched-out world, then he would also have experienced a stretched-out canvas. In that case, the distortions should have canceled each other out: Just as El Greco would have seen real-world figures as elongated, so too would he have seen his paintings as elongated, and so the real-world distortions he experienced would never have transferred to his reproductions. The distortions in El Greco's paintings, then, must have some alternative explanation beyond a literal perceptual distortion. (2014, p. 39)

When we turn to BSE experiments involving a 'perceptual' condition, we are faced with a similar situation to interpreting El Greco's paintings. In these conditions BSE tasks are created so that the image participants manipulate appear to them just as an image in a mirror would; the digital photo used is manipulated to be exactly the same height as participants' body appears in the mirror.

If AN patients really perceived their mirror reflection in a distorted manner, this distorted perception should also apply to viewing images which are manipulated to look like mirror reflections. If both mirror reflections and the manipulated images are perceived in a distorted manner then, just as Firestone and Scholl argue with El Greco's paintings, the distortions should cancel each other out. However, no cancelling out is evident—oversized distortion *is* seen in the BSE results. This rules out distorted self-perception, suggesting the problem occurs elsewhere along the cognitive path.

7.3 The Influence by Affect Hypothesis

It's still too early to offer a complete answer for how the LTB becomes distorted in AN. However, I will discuss some evidence that suggests affect might play a role. A similar suggestion to the one I will make can be found in Metral and colleagues' (2014) paper. After finding a correlation between body schema size and weight recovery (i.e. the current BMI less the minimum BMI), they suggest the following explanation:

In anorexic patients, weight regain (with calorie fear and false beliefs about being "obese") is associated with limbic and paralimbic activation and has consequences on emotional arousal (i.e. the presence of obsessive and depressive symptoms). During the weight recovery phase, the AN inpatient group's depression and anxiety scores were pathological. One could imagine that this emotional arousal interferes with visual and somesthetic sensory inputs that underpin body perception and motor expression. (2014, p. 9)

Metral and colleagues' particular interpretation of their finding is somewhat problematic. As discussed, AN patients do not have a general deficit in their visual inputs and there are no somesthetic sensory inputs that deliver consistent spatial content for emotional arousal to interfere with. However, the idea that affect plays some role in distorting the spatial content of the LTB is an interesting proposal.

This particular hypothesis blends nicely with a series of BSE experiments done in the 90s. Taylor and Cooper (1992) conducted the first of these experiments on a group of 85 healthy female college students. Participants first completed a BSE task. They were then split into groups and underwent either a positive or negative mood induction procedure involving reading statements with either miserable connotations (e.g. "I feel ashamed of things I've done") or pleasant connotations (e.g. "I feel that I am a nice person") and completing open-ended self-referent statement (e.g. "I feel a failure because...", "I feel proud of myself because...") (p. 55). Participants then re-estimated their body size using the same BSE method.

The researchers found that "compared with the induction of a positive mood state, the induction of a negative mood state led to greater disturbances in body size perception in the form of a tendency towards overestimating body size" (p. 57). Furthermore, they found:

among the women who received the negative mood condition, compared with those with little or no concern with their body shape, for those with such concerns the induction of low mood led to greater disturbances in body size perception in the form of overestimating their body size significantly more ... (p. 53)

This effect of negative mood induction on overestimation was not found to be statistically significant (p. 55). However, the study has since been replicated (with statistical significance reached) (Plies & Florin, 1992; Baker, Williamson, & Sylve, 1995; see also: McKenzie, Williamson & Cubic, 1993).

Relevant to the connection between body concern, negative mood induction and body size overestimation, Baker, Williamson, & Sylve (1995) compared subjects classified as either high or low in body dysphoria.²¹ They found that negative mood induction *only* increased body size overestimation in their high body dysphoria group (p. 755).

²¹ Researchers screened 344 female undergraduate students to arrive at two groups, with 36 subjects in each. They write, "undergraduate females were screened for the presence and absence of body dysphoria using the *Body Shape Questionnaire* (BSQ; Cooper, Taylor, Cooper, & Fairburn, 1987). Subjects high in body dysphoria were defined by a score greater than one standard deviation above the mean (a score greater than 110) on the BSQ and subjects low in body dysphoria were defined by a score less than one standard deviation below the mean (a score less than 50) on the BSQ" (p. 749). The BSQ asks a range of questions, e.g. "Have you been afraid that you might become fat (or fatter)", "Have you avoided running because your flesh might wobble", "Has eating sweets, cakes, or other high calorie food made you feel fat", "Have you felt ashamed of your body?" and "Have you vomited in order to feel thinner" (Cooper et al., 1987).

Although no tactile form or body schema tests were conducted, these experiments might be an example of the spatial content of the LTB being altered. This would suggest that, even for healthy controls, the spatial information of the LTB can be altered through influence by affect. How much the LTB is susceptible to this influence through affect is possibly a product of how much body concern/dysphoria someone has. AN patients' LTBs would be more highly susceptible to such alteration because, as a group, they have such high body concern/dysphoria.

Of-course these distortions of the body percept through affect might happen in a direct manner, leaving the dimensions of the LTB intact. It might even be that the evident shift in BSE results is caused by some other factor, not related to body percept size e.g. demand characteristics of the experimental setup. If either of these scenarios were the case, then we are still at a loss for an explanation for how AN patients' LTBs become distorted. The way to determine between these possibilities is, of-course, through experiment (see 9.3).

8. Why Doesn't Self-Viewing Update the LTB?

I argued that AN patients do not have a perceptual deficit which causes them to actually *see* their bodies as wider when they look in a mirror. Given that vision undoubtedly plays a strong role in updating the LTB, one obvious question is why, upon viewing their thin bodies in the mirror, don't AN patients' LTBs update to reflect their true dimensions?

As in the case of answering how patients' LTBs become distorted in the first place, I won't be able to offer a complete solution. I will, however, discuss preliminary evidence that provides some insight into the issue. Using fMRI, Sachdev and colleagues (2008) investigated the brain processing of AN patients when viewing images of themselves. Patients processed non-self images similarly to the control group. However, when processing images of themselves, AN patients "do not appear to engage the attentional system or the insula, and suppress emotional and perceptual processing of the information" (2008, p. 2167). Previous studies have indicated that the insula is involved in processing images of oneself (Devue et al., 2007).

Sachdev and colleagues conclude from their findings:

this differential processing ... might explain why AN patients have a distorted view of their body image. The reduced perceptual processing may provide the basis for perceptual disturbance in relation to body shape which AN patients show, and the insula inactivity the basis of failure of feedback to correct their self-image disturbance. (2008, p. 2167)

It seems plausible that this distorted self-image processing also applies to instances of mirror exposure, helping explain why such experiences fail to properly update the LTB. Of-course further investigation is needed to understand the exact nature and cause of this inhibited processing and what this

means in terms of the LTB hypothesis, however Sachdev and colleagues' work is certainly a step in the right direction.

This altered processing of self-images might also explain why patients continue to overestimate body size in perceptual BSE conditions (while exposed to a mirror). Perhaps patients continue to estimate their size based off the body percept rather than the mirror image. The body percept maintains its faulty dimensions, failing to update (via the LTB) due to aberrant processing of the mirror image.

We can also extend this explanation further to account for evidence of AN patients overestimating body size *more* in perceptual BSE conditions than memory BSE conditions (Øverås et al., 2014). It's known that subjects with eating disorders respond to mirror exposure with a strong increase in negative affect (Vocks et al., 2007). So perhaps the size of the body percept increases in perceptual BSE conditions, due to increased negative affect (arising from mirror exposure) distorting the LTB (as hypothesized in 7.3). This increase in the size of the body percept, in turn, causes even greater overestimation in the BSE task.

An alternative to the view that patients have a deficit in self-image processing due to altered insula function is that veridical visual input simply isn't sufficient to override the underlying disturbance. It might be that visual input only *temporarily* corrects the LTB (before it falls back to being distorted) or it might be that the underlying disturbance is too great to override at all. This issue should be further explored using self-image exposure techniques.

9. Concluding Remarks and Future Directions

In this paper, I reviewed evidence that shows AN patients exhibit oversized body percepts, body schemas and tactile forms. I claimed that the spatial content of these representations is dynamic, requiring a more stable representation (similar to O'Shaughnessy's LTB) to store the default parameters of the body. I went on to suggest that these dynamic representations might also be considered short-term. If this is the case, then the need for an LTB is even clearer—it stores the spatial content used to generate these short-term representations. Nevertheless, the existence of the LTB does not rest on this short-term characterisation. Even if empirical research shows that the body percept, body schema and tactile form *store* spatial content long-term, their dynamic nature (especially the body schema) still might require a more stable LTB. Finally, I suggested AN patients' LTBs might become distorted through influence by affect.

Before outlining some future directions for research suggested by this paper, I will briefly discuss a few promising new areas of research in AN and distorted body representations. One area of research relates to AN patients' susceptibility to the *rubber hand illusion* (RHI). During the RHI a participant sits with their left arm resting on a table in front of them, hidden from view by a screen (Botvinick & Cohen, 1998). In front of them is placed a realistic life-sized rubber hand. While the subject looks at the rubber hand, the experimenter strokes both the rubber hand and the subject's hand simultaneously with two matching

paintbrushes. After some time, participants report that they begin to feel a sense of bodily ownership over the rubber hand: they feel as if it belongs to them, or is a part of their body (Botvinick & Cohen, 1998; Longo et al., 2008).

The cognitive processes underlying the rubber hand illusion are widely considered to involve body representations (de Vignemont, 2007; de Preester & Tsakiris, 2009; Tsakiris, 2010; Carruthers, 2013). However, which representations are involved and *how* is still up for debate (Carruthers, 2009; Zopf et al., 2011; Apps & Tsakiris, 2014; Kiltner et al., 2015). Recent research seems to suggest that AN patients have a higher susceptibility to the RHI (Eshkevari et al., 2012; 2014; Keizer et al., 2014; 2016; Zopf et al., 2016; also see: Mussap & Salton, 2006). First and foremost, future research should explore what relationship the RHI has to the LTB. After this, the link between AN patients' LTB distortion and susceptibility to the RHI can, perhaps, be elucidated.

Another promising area of research in AN relates to findings of disturbances in the way patients process interoceptive signals (Pollatos et al., 2008; Strigo et al., 2013; Crucianelli et al., 2016). Altered processing of interoceptive signals in patients has been linked to impaired function of the insula (Wagner et al., 2008; Strigo et al., 2013; Kerr et al., 2016). It's not yet clear what relationship this altered processing has to the LTB hypothesis. As I have argued, the role of the LTB is to track size and shape information on the body and there are no interoceptive signal which carry this content. Nevertheless, the processing of interoceptive signals, sense of bodily ownership in the rubber hand illusion and body representations are three deeply interrelated areas of cognition (Moseley et al., 2008; Tsakiris, Tajadura-Jiménez & Costantini, 2011; Crucianelli et al., 2013; Rohde et al., 2013; Suzuki et al., 2013). As such, altered processing of interoceptive signals may prove relevant to the issue of distorted body representations and is certainly an area worthy of further empirical investigation.

One issue that needs resolving before a modernised LTB framework can be accepted relates to the *form* of these body representations. Take the body schema, for example. It has been argued that because "muscles work in functional groups to achieve actions", motoric mental representations must be structured into *functional units*, "according to which body parts move together" (de Vignemont et al., 2009, p. 503; de Vignemont, Tsakiris & Haggard, 2005; Cardinali et al., 2009). Therefore, the body schema would take the form of functional collections of disparate muscles and body parts. This is contrasted against the tactile form, for example, which is said to take the form of 2 dimensional surfaces, segmented into *categorical* parts (de Vignemont et al., 2009; Longo, 2015).

The question that arises is what form the LTB takes and how it can feed into these differently formatted body representations?²² This question is especially pressing in regards to feeding the body schema. Is the LTB already in a

²² Thanks to reviewer 1 for pointing this out.

functionally organized motoric form? If not, how can its content be used by the body schema system?

I envision the LTB as taking on a neutral form, one that isn't preformatted in terms of functional motoric units. To understand how LTB content is transformed for the body schema, it must be remembered that according to the short-term hypothesis I suggest, the body schema system makes use of different kinds of content to generate appropriate motoric representations *on the fly*. So rather than content being passed between two representations with fundamentally different forms, content is being integrated to *generate* a representation with an appropriate (motoric) form.

We have reason to suspect that the body schema system is exceptionally good at reformatting different kinds of content into the appropriate, functionally relevant blocks. Not only is content regarding disparate muscles grouped together to create action relevant groupings, size and kinetic content regarding functionally relevant tools is also integrated to form functionally coherent representations. During action this content is imported from the sensory systems (primarily visual and tactile) and converted into the appropriate format so that the relevant tools can be used as extensions of the body.

As such, the constant reformatting of different types of content is a key feature of the body schema system. Body size and shape information stored in the LTB would represent just one more kind of content that needs converting. How exactly this format neutral content is converted into the different forms found in the body percept, schema and tactile form is a fascinating issue that needs further attention. My central point is only that the body schema system appears more than capable of handling such a task.

If the LTB hypothesis outlined in this paper is correct then focusing on the LTB, rather than any specific dynamic representation, will be the most effective target for treatment of distorted body representations in AN. The first step, of-course, is to empirically verify the claims I have made in this paper: that the LTB exists, that it causes the evident dynamic representation distortion and that it becomes distorted through influence by affect. After this, we must better understand how the LTB updates, how it can be manipulated and what *the specifics* of its relationship to affect are. Only then, will we be in a position to propose avenues for treatment.

However, before future research is dedicated to understanding these issues, the claims I've made need empirical verification. In order to contribute to this task, I have included three suggestions for experiments. These experiments won't prove all the claims contained in this paper. However, they are a step in the right direction.

9.1. Testing distortion of alternative body schema dimensions

The body schema experiments on AN patients have successfully shown that their shoulders are represented as wider. However, just as Spitoni and colleagues

modified a TDE task in order to show that the tactile form had *specific* spatial distortions (i.e. wider hips and abdomen), alternative distorted spatial dimensions of the body schema should be explored.

Different body scale dimensions determine different abilities. Just as shoulder width determines face-forward aperture-passing ability, waist size determines sitting in-between aperture ability (e.g. on a chair with sides) and body depth (i.e. abdomen depth) determines side-stepping through aperture ability (Franchack & Adolph, 2013). Experimental setups that run motor imagery (or motor action) experiments on these alternative tasks would show that AN patients' body schemas have distorted dimensions beyond shoulder width.²³ Furthermore, given that the waist and abdomen size is more distorted when it comes to the body percept, we should see an even greater difference between controls and AN patients in these conditions (Molinari, 1995; Spitoni et al., 2015, p. 184).

If it can be determined that distortions are evident in these alternative body schema dimensions, then these results can be compared against BSE tasks asking participants to estimate these dimensions of their bodies. If a within-subject match is found between body schema dimensions and body percept dimensions, as Keizer and colleagues (2013) showed with shoulder width, then there is further support for my hypothesis that the spatial content for each representation is imported from the one source, the LTB.

9.2. Testing tool extended aperture-passing affordances

Perception of aperture-passing affordance coheres with the boundaries of the body schema. This includes when the body schema has incorporated tools or other objects. For example, Hackney, Cinelli & Frank (2014) showed that when walking through apertures while holding a serving tray that is wider than their shoulders, participants' critical point adapted to the width of the tray.

By adopting this experimental paradigm, one could conduct an experiment on AN patients where aperture passing is tested using a condition that extends the body schema. If the overestimation seen in AN aperture-passing experiments reflects a *general* distortion of the body schema, then this effect should remain even if the task involves holding an item that is wider than they estimate their shoulders to be (i.e. wider than their LTB's shoulder width). However, if, as I have claimed, the distortion happens at the LTB and, as such, only applies to the dimensions of the *body* (rather than the person-plus-object schema) then during estimation of aperture-passing affordance in the tool holding condition, AN patients' critical point should decrease closer to the standard critical point found in healthy controls by Warren and Wang (1987).

9.3. Testing modification of the LTB through affect

²³ For example, Franchack & Adolph's (2013) paradigm for testing affordances for passing through apertures sideways could be adopted.

Taylor and Cooper (1992) modified body size estimation on a group that didn't have eating disorders through negative mood induction. After inducing a negative mood, they found that body percept size (as measured by a BSE task) increased, especially on those participants with high body concern.

If a similar experiment could be setup with additional tasks to test for tactile form and body schema size (i.e. TDE and affordance tasks), then this would lend support for the hypothesis that affect can distort the LTB, which then affects the spatial content of the dynamic body representations. By including conditions with tactile form and body schema tasks where the patients are unaware of the goal of the experiment, this helps to rule out the possibility that overestimation of body size after negative mood induction is a result of demand characteristics or a direct reflection of *attitude* rather than representation size.

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