THE MECHANISMS UNDERLYING ALTERED SOMATOPERCEPTION AND SOMATOSENSATION IN HEALTHY AND SUBCLINICAL POPULATIONS

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ABSTRACT

Manipulating somatic representations has been found to alter somatic experiences; however, the precise mechanisms underlying these altered somatic experiences are as yet unclear. This thesis primarily investigated the mechanisms underlying altered somatic experiences following illusions that manipulated perception of the body representation. The current thesis also addressed individual differences in somatic perception across individuals with propensities towards various clinical conditions, including amplified somatosensory sensitivity and medically unexplained symptoms (MUS).

The pilot investigation in Chapter 3 provided evidence for susceptibility and ownership towards somatic illusions generated using the MIRAGE mediated-reality system, thus validating manipulations induced using this system. In Chapter 4, longer and shorter body representations were judged as veridical (or normal) following stretched and shrunken illusions respectively, while in contrast to early studies ownership was not lost as a result of the illusory manipulations. An association between self-reported somatic sensitivity and illusion strength was also observed for females, with females reporting increased somatic sensitivity being more susceptible to the illusion.

Chapter 5 demonstrated that illusory alterations of body shape and size improved perception of near threshold tactile stimuli. However, changes in tactile perception were driven by differing mechanisms when body size at the site of stimulation was altered, whilst similar mechanisms drove this change when body size away from the site of stimulation was altered. Interestingly, a detached condition (in which the finger-tip and stump were disconnected) resulted in a significant reduction in overall positive reports of feeling tactile stimuli. Finally, overall false-touch reports and reduced sensitivity (*i.e.*, the

inability to discern between touch present and absent trials) were found to be characteristic of those with propensities towards MUS.

Chapter 6 demonstrated that a purely visual illusion, in the absence of any real somatic input, did not interfere with external tactile perception or lead to different response patterns between individuals with increased or decreased tendencies towards MUS.

The thesis provides evidence for the dynamic and bidirectional flexibility of the body representation by providing direct evidence for the immediate updating of the body representation following size-altering illusory manipulations. These illusions also altered external somatic sensations via different underlying mechanisms and reflected individual differences in response patterns between healthy and sub-clinical populations, thus suggesting that susceptibility to such illusions may be clinically relevant, and useful in identifying the nature various psychological pathologies.

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LIST OF ABBREVIATIONS

3PP	Third person perspective
AHS	Alien hand syndrome
BIID	Body integrity identity disorder
CRPS	Complex regional pain syndrome
ERP	Event related potentials
fMRI	Functional magnetic resonance imaging
IVR	Immersive virtual reality
LED	Light emitting diode
mPFC	Medial prefrontal cortex
MSE	Modality shift effect
MUS	Medically unexplained symptoms
PCC	Posterior cingulate cortex
Pcu	Precuneus
RHI	Rubber hand illusion
S1	primary somatosensory cortex
SCR	Skin conductance responses
SDQ-20	Somatoform dissociation questionnaire-20
SOA	Stimulus-onset-asynchronies
SPL	Supernumerary phantom limbs
SSAS	Somatosensory amplification scale
STAI-T	State-trait anxiety inventory- trait scale
TMS	Transcranial magnetic stimulation
TPJ	Temporoparietal junction

CHAPTER 1

GENERAL INTRODUCTION (i)

Our daily somatic experiences require a sense of ownership towards the body and its parts, making it an integral aspect of one's identity and self-awareness. Although somatic interactions with objects and people in the environment may seem to reflect reality, numerous clinical conditions (*e.g.*, somatoparaphrenia, phantom limb syndrome, body integrity identity disorder, chronic pain etc.) have provided evidence for dysfunctional perceptions of the body (Armel & Ramachandran, 2003; First, 2005; Moseley; 2005; Vallar & Ronchi, 2009). Such conditions, give rise to altered perception of the body including disownership of an existing body part, ownership towards additional limbs, as well as distorted perceptions of body shape and size, which may in turn create disturbed bodily experiences and sensations.

Illusions that experimentally alter somatic perception create convincing distortions of the body under controlled laboratory conditions (*e.g.*, the Rubber Hand Illusion (RHI); Botvinick & Cohen, 1998). Understanding the mechanisms and processes by which bodily illusions are generated and alter somatic perceptions provides a systematic means of investigating distorted body experiences, primarily in clinical conditions. In addition to shedding light upon the mechanisms underlying the development of distorted somatic experiences, somatic illusions can also alter somatosensation, however, the precise mechanisms by which different bodily illusions can alter bodily perception and sensation are as yet unclear and therefore require closer examination (Kennett, Taylor-Clarke & Haggard, 2001).

This thesis attempts to contribute to, and further our understanding of the mechanisms underlying distorted somatic experiences. Chapter 1 begins by outlining somatic distortions experienced by both healthy individuals and those with a clinical diagnosis of distorted perceptions of their body, and then focuses on the use of experimentally induced somatic manipulations/illusions that act as tools to investigate these phenomena under laboratory settings. Chapter 2 discusses literature on altered somatosensation, focusing particularly on how somatic manipulations/illusions may alter somatosensation. In line with previous literature on differential response patterns to somatic illusions (Burrack & Brugger, 2005; McKenzie & Newport, 2015) and somatosensation (Brown, Brunt, Poliakoff & Lloyd, 2010) in healthy and clinical populations, the chapter also provides an overview of related individual differences. The following four chapters (3, 4, 5, and 6) report the empirical investigations examining the mechanisms by which somatic illusions altered somatic perception and somatosensation while chapter 7 discusses and interprets the overall findings in relation to previous literature and proposed theories.

1.1 Self-awareness

Humans possess the ability to be aware of and recognise themselves from other individuals and objects in the environment. Such an ability is a result of each individual having more access to his/her own body compared to other bodies and objects (de Vignemont, 2011). This gives each individual a sense of self-awareness. (Giummarra, Gibson, Georgiou-Karistianis & Bradshaw, 2008). This sense of self-awareness and recognition is evident even in the presence of fake and manipulated representations of

limbs as well as when participants view themselves from third person perspectives (3PP) through either a mirror (Bertamini, Berselli, Bode, Lawson & Wong, 2011) or via head-mounted displays (Preston & Newport, 2012). Self-awareness is essential for successful interaction with objects and persons in the environment. This includes having a sense of ownership and embodiment towards the body and its' constituent parts. Ownership refers to the perception that body parts phenomenologically and functionally belong to oneself (Giummarra et al., 2008) while embodiment is a related but slightly distinct concept that has been referred to differently in various contexts (Kilteni, Groten & Slater, 2012). In this thesis, however, embodiment is concerned with how the body and its parts are mentally represented; *i.e.*, the feeling of having a body and controlling the body (Arzy, Seeck, Ortigue, Spinelli & Blanke, 2006c; Giummarra et al., 2008; Kilteni et al., 2012). These constructs are maintained by a flow of information received from sensory systems including the interoceptive, vestibular, proprioceptive, tactile and visual sensory systems, and are associated with activity in the premotor (Ehrsson, Spence & Passingham, 2004) and parietal cortices (Lloyd, Morrison & Roberts, 2006) as well as the temporoparietal junction (TPJ; Arzy, Thut, Mohr, Michel & Blanke, 2006b). For example, experimental studies inducing ownership over fake limbs have shown bilateral neural activity in the ventral premotor and posterior parietal cortices (Ehrsson et al., 2004; Ehrsson, Holmes, & Passingham, 2005; Ehrsson, Wiech, Weiskopf, Dolan & Passingham, 2007) while temporary virtual lesions created by single pulse transcranial magnetic stimulation (TMS) in the right TPJ have been found to reduce illusory ownership over fake limbs, but conversely to improve ownership over neutral objects, suggesting that disrupted activity in the TPJ may have created ambiguity in what may and may not be perceived as a part of

an individual's body (Tsakiris, Costantini & Haggard, 2008). These examples demonstrate the involvement of brain regions including the premotor and parietal cortex and the TPJ in maintaining a coherent sense of self. Damage to these regions or related areas could therefore lead to disorders of distorted body states and body ownership/embodiment that reflect altered states of self-awareness and misinterpretation of sensory inputs. Such altered states of self-awareness are seen in disorders including asomatognosia (Berlucchi & Aglioti, 1997), somatoparaphrenia (Vallar & Ronchi, 2009), unilateral neglect (Bartolomeo, Perri & Gainotti, 2004), supernumerary phantom limbs (Brugger, 2005) and alien hand syndrome (Park, Kim, Kim, Jeong & Jung, 2012). Body integrity identity disorder (First, 2005) does not always involve cortical damage, however, it has been discussed in the review below, as it is a disorder of ownership and embodiment. Chronic pain - a further form of somatic misperception characterised by distorted perceptions of perceived body size (Peltz, Seifert, Lanz, Müller & Maihöfner, 2011) is also included in the following review, as it is suggested to be associated with altered cortical representations (Flor et al., 1995; Pleger et al., 2005; Pleger et al., 2006).

1.1.1 Disorders of body ownership and embodiment

a) Asomatognosia and Somatoparaphrenia

Asomatognosia is characterised by a feeling that parts of one's body is missing or has disappeared from awareness (Arzy, Overney, Landis & Blanke, 2006a). These deficits are apparent on the contralesional side of the body following damage to the right hemisphere, particularly the posterior parietal cortex (Berlucchi & Aglioti, 1997; Arzy et al., 2006). Indeed functional magnetic resonance imaging (fMRI) studies have shown the parietal and premotor regions (that receive direct parietal input) to be involved with limb

ownership (Ehrsson et al., 2004; Ehrsson et al., 2007). Great variation is seen in the degree of deficits associated with asomatognosia. For example, Arzy et al., (2006a) reported a patient who believed her hand was transparent, as she reported parts of her arm to have disappeared, allowing her to see the table on which her arm was resting, while Wolpert, Goodbody and Husain (1998) reported a patient who believed her arm and leg drifted into space unless she was able to see them.

In some clinical cases the disowned limb can be attributed to another individual- a condition referred to as somatoparaphrenia (Giummarra et al., 2008; Vallar & Ronchi, 2009). While somatoparaphrenia is often associated with right hemispheric damage resulting in the deficit on the contralesional (left) side of the body (Vallar & Ronchi, 2009) a few instances of somatoparaphrenia for the right side of the body, following left brain lesion have also been reported (Miura et al., 1996; Schiff & Pulver, 1999). Numerous case reports have shown that following a right hemispheric stroke, patients attribute ownership of the contralesional side of the body or body parts to family members, including the son (Daprati, Sirigu, Pradat-Diehl, Franck & Jeannerod, 2000) nephews (Paulig, Weber & Garbelotto, 2000), nieces (Bottini, Bisiach, Sterzi & Vallar, 2002) and even to unrelated individuals such as other patients in the hospital (Moro et al., 2004) or interestingly even to a ‘reptile’ (Rubinstein, 1941). The disownership associated with somatoparaphrenia has also been found to extend to inanimate objects that were once associated with the patient’s body. Aglioti, Smania, Manfredi and Berlucchi (1996) reported the case of a female who denied ownership of her rings when worn on the contralesional (left) hand but not when worn on the right. This effect was, however, only seen for objects that had previously been in contact with the body compared to other

objects (*e.g.*, combs and pins), thus suggesting that the mental representation one holds of his/her body may perhaps also include objects that are in contact with the body.

b) Unilateral neglect

Unilateral neglect is a neurological disorder characterised by attentional deficits and a failure to respond to stimuli on the contralesional side of the body (Halligan, Fink, Marshall & Vallar, 2003). Neglect is primarily seen following damage to the right inferior parietal region (Danckert & Ferber, 2006). As a result, patients attend to ipsilateral stimuli and behave as though one side (the contralesional side) of their body no longer exists (Danckert & Ferber, 2006). Indeed, virtual lesions created by TMS in the parietal cortex have been found to reduce detection of contralesional target stimuli (Hilgetag, Théoret & Pascual-Leone, 2001). Some neglect patients display severe deficits in personal tasks that include the inability to dress or shave the contralesional side of their body or face and eat from only right (ipsilateral) side of the plate, even though the contralesional hand is not paralysed (Driver, Vuilleumier & Husain, 2004). Other forms of difficulties include impairments responding to events or objects that are beyond personal space (Bisiach, Perani, Vallar & Berti 1986; Cowey, Small & Ellis, 1994; Beschin & Robertson, 1997). Similar spatial biases are seen in experimental tasks conducted to examine neglect. Typically, these tasks require responding to both ipsilateral and contralesional stimuli. Cancellation tasks require patients to detect and cross out target stimuli (*e.g.*, stars) presented in the midst of a series of distractors (Ferber & Karnath, 2001). The line bisection task requires patients to place a mark at a point they think is the mid-point on a horizontal line (Binder, Marshall, Lazer, Benjamin & Mohr, 1992). Findings on these tasks have revealed that patients with unilateral neglect fail to

cancel targets on the contralesional side of the page, and place their midpoint mark on the ipsilateral side of the actual midpoint respectively. Furthermore, when asked to draw or copy common objects (such as the face of a clock, or a flower), patients fail to draw and copy the contralesional side of the image (Halligan, Marshall & Wade, 1990). While spontaneous improvement is seen in a small percentage of patients during the acute phase of the disease (Farnè et al., 2004) a large proportion of patients at the chronic stage are still left with debilitating symptoms. Remarkable improvement has, however, been shown following a period of adaptation with prismatic lenses (Rossetti et al., 1998). Depending on the direction of deviation of the prism wedges, patients' visual fields would either be shifted to the right or left, thus bringing previously neglected regions into awareness.

c) Supernumerary phantom limbs

Supernumerary phantom limbs (SPL) refer to the experience of an extra illusory limb (Brugger, 2005) in addition to the real limb. Perception of such limbs is extremely rare. In fact Miyazawa, Hayashi, Komiya and Akiyama (2004) reported only 20 cases of SPL in the past 70 years. SPL could arise following either left or right hemispheric lesions (Frederiks, 1963), however, their occurrence is more common following right cerebral lesions (Canavero, Bonicalzi, Castellano, Perozzo & Massa-Micon, 1999) including the right frontomesial cortex (McGonigle et al., 2002), the right basal ganglia (Halligan, Marshall & Wade, 1993), and the right subcortical regions (Khateb et al., 2009). SPL are usually reported on the same side as the paralysed limb following strokes (Antoniello, Kluger, Sahlein, & Heilman, 2010). Although movements of the phantom are usually automatic and involuntary by nature (Dieguez & Blanke, 2011) there are instances in which the SPL may mimic movements of the contralesional real limb or

follow movements of the ipsilateral real limb (McGonigle et al., 2002). Interestingly however, Khateb et al. (2009) and Staub et al. (2006) have reported cases in which patients that were paralyzed on one side were able to move their SPL intentionally whenever they wished to move it.

d) Body integrity identity disorder

Body integrity identity disorder (BIID) is characterised by an incorrect belief that a healthy limb requires amputation (First, 2005). Patients with BIID perceive a healthy limb to be incomplete or in some instances even too complete and amputation is therefore expected to restore the ideal body image (First, 2005; body image discussed in section 1.3). While BIID is found to affect both males and females, it is more predominantly reported in males (First, 2005; Blanke, Morgenthaler, Brugger & Overney, 2009). The feelings of disownership towards body parts and the urge to have them amputated usually begin at childhood and continue through adulthood, causing significant levels of distress (First, 2005; Blanke et al., 2009). Data by First (2005) report the following statements from patients, “I feel like an amputee with natural prostheses — they are my legs, but I want to get rid of them — they don’t fit my body image”, and, “I felt like I was in the wrong body; that I am only complete with both my arm and leg off on the right side”. These statements may indicate that BIID may in fact result from a perceived mismatch between patients’ experience of their own body and their ideal body, and is found to be the most common reason for a desire for amputation (First, 2005; Bayne & Levy, 2005). Alternatively, there is also evidence suggesting that limb disownership could be triggered by an attraction towards amputees or being an amputee (Money, Jobaris & Fruth, 1977). In line with this, findings by First (2005) have also provided evidence for a sexual

component for the urge for limb amputation with 15% of his patient sample reporting arousal as the primary reason for a desire for amputation. Although extremely uncommon, some patients suffering from BIID also hold incorrect beliefs that a healthy limb appears ugly or diseased and the desire for amputation therefore stems from a need to get rid of such a limb. Findings by First (2005) found only a single patient out of a group of 52 to report ugliness as a reason for amputation. Nevertheless, these findings point towards body dysmorphic disorder (BDD; Phillips, 1996) being a possible reason for the need for amputation. More recent investigations have provided both direct and indirect evidence indicating that BIID may in fact be a neurological disorder. For example, McGeoch et al. (2011) found somatosensory stimulation on the affected limb to be associated with a corresponding decrease in activity in the right parietal lobule. The authors also observed reduced skin conductance responses (SCR) in the body part desired to be amputated in patients with BIID compared to controls. These findings suggest that dysfunctional activity of right super parietal lobule may have led to abnormal sympathetic blood flow which was in turn reflected by changes in SCR (Brang, McGeoch & Ramachandran, 2008). While the studies discussed above propose a number of models that may explain the cause of BIID, medical and psychological intervention and treatment programs have only provided partial relief for the symptoms (Braam, Visser, Cath & Hoogendijk, 2006).

e) Chronic pain

Chronic pain is defined as pain that lasts longer than a period of three months or longer than the expected healing time (Merskey, Lindblom, Mumford & Sunderland, 2014). In contrast to acute pain (thought to play a protective role) chronic pain is

considered a disease on its own (Niv & Devor, 2004). Chronic pain conditions include phantom limb pain, complex regional pain syndrome (CRPS), chronic lower back pain and osteoarthritis. These chronic pain states are usually associated with distorted perceptions of the appearance of the body (Lotze & Moseley, 2007). Approximately 80% of amputees experience phantom limb pain, which they describe as being moderate or extremely severe (Ephraim, Wegener, MacKenzie, Dillingham, & Pezzin, 2005). Amputees reporting phantom limb pain also report the phantom limb to feel heavy, swollen, stuck in a certain position or even to be missing digits or entire parts (Giummarra, Gibsonb, Georgiou-Karistianisa & Bradshaw, 2007). CRPS on the other hand is not associated with injury, however, patients complain of swollen limbs in the absence of any real swelling (Lotze & Moseley, 2007). Indeed, when asked to select a photograph depicting the appearance of the affected limb from a series of images, the selected image is usually bigger than the limb (Moseley, 2005). Similarly, when asked to resize a photograph to match the size of the affected limb, an image approximately 106% of the original size is selected (Lotze & Moseley, 2007). Similar to phantom limb pain, CRPS patients may also experience the painful limb to be missing a part (Lewis, McCabe & Blake, 2005). Chronic lower back pain and osteoarthritis are also associated with distorted perceptions of the body with patients stating the painful body part to feel swollen (Lotze & Moseley, 2007) and smaller compared to healthy controls (Gilpin, Moseley, Stanton & Newport, 2014) respectively. As a result experimentally altering body size has been found to modulate pain (Moseley, Parsons, & Spence, 2008b) and temporarily alleviate pain (Preston & Newport, 2011). This suggests that pain relief in

such states could be a result of a correction of the disease related representation of the body (Preston & Newport, 2011).

f) Alien hand syndrome

Patients with alien hand syndrome (AHS) experience their limbs to be moving involuntarily resulting in unintended actions that may appear purposeful (Biran & Chatterjee, 2004). The alien limb may reach for and grab objects in the environment resulting in the patient having to use the unaffected limb to open the fingers of the alien limb and release the objects (Kumral, 2001). Sometimes the alien limb may even choke the patient in their sleep (Banks et al., 1989) and conflict the actions of the opposite unaffected limb resulting in patients often referring to the affected limb in the third person (Biran, Giovannetti, Buxbaum & Chatterjee, 2006). The disorder is most commonly reported following damage to medial frontal lobes and the corpus callosum (Goldberg, Mayer & Toglia, 1981; Suwanwela & Leelacheavasit, 2002) while there is also some evidence for AHS following parietal damage (Carrilho et al., 2001). Medial prefrontal damage especially on the left has been found to be associated with grasping and compulsive utilisation behaviours that are characterised by a tendency towards using objects spotted in the environment without any purpose. For example, the patient may grab an apple that is placed on a table beside the him/her, peel it and then eat it even though he/she is not hungry (Boccardi, Sala, Motto & Spinnler, 2002). Callosal damage on the other hand is found to be commonly associated with intermanual conflict such that the alien limb counteracts voluntary actions performed by the healthy unaffected limb. Such actions include pulling off a jacket that had just been put on or closing a door that was just opened (Barbeau, Joubert &f Poncet, 2004). Damage to the parietal regions has

been found to interfere with motor function most probably due to impaired sensory integration and feedback (Martí-Fàbregas et al., 2000). Biran et al. (2006) identified three factors that drive alienation in AHS: (1) the limb should be disinhibited and disproportionately reactive to external stimuli in the environment leading to abnormal utilisation behaviours; (2) these disinhibited limb actions should appear organised and purposeful despite there being no goal directed intentions; (3) and finally the patient should be aware of the actions carried out by the limb. Such aberrant behaviours of the affected limb are found to increase in the presence of a secondary task most probably due to increased fatigue and anxiety (Giovannetti, Buxbaum, Biran & Chatterjee, 2005).

1.2 Investigating ownership and embodiment under laboratory settings

The alterations in somatic perception discussed above provide evidence for flexible body representations in patients with clinical conditions. Although such somatic distortions may only seem to be a sign of pathology, numerous experimentally induced somatic illusions have demonstrated that distorted or anomalous bodily experiences including altered states of ownership and embodiment are in fact a characteristic feature of healthy cognition (Longo, 2013). Somatic illusions are created following cross-modal manipulations to sensory inputs and give rise to altered bodily experiences that can range from simple perceptual manipulations to ownership distortions in which non-bodily objects such as fake or altered body parts are felt to belong to one's own body. By providing a means of examining the conditions under which body representation is disturbed, somatic illusions act as powerful tools in investigating the mechanisms underlying the development and maintenance of distorted body experiences (Kilteni,

Maselli, Kording & Slater, 2015). The next section provides examples of illusory somatic experiences.

1.2.1 Somatic illusions

The Parchment skin illusion is an audio-tactile illusion that results from incongruent sensory inputs. In this illusion, skin texture is felt to change when participants rub their hands together in synchrony with grating sounds of varying frequencies heard via ear-phones (Jousmäki & Hari, 1998). The cutaneous rabbit illusion is another classic illusion in which touch is mislocalised. In this illusion, when a series of taps are applied on discrete locations of the skin, illusory taps are perceived between the locations of stimulation as if a rabbit hopped along successive locations (Geldard & Sherrick, 1972). The illusory taps have indeed been found to activate corresponding primary somatosensory cortex (SI) regions (Blankenburg, Ruff, Deichmann, Rees & Driver, 2006). Somatic perception may therefore not often reflect reality, but rather be accompanied with illusory sensations (Miyazaki, Hirashima & Nozaki, 2010) that may somatotopically activate SI regions. Lackner (1988) demonstrated that vibration of the biceps and triceps tendon created illusory feelings of forearm extension and flexion respectively, suggesting that tendon vibration generated signals specifying muscle lengthening. When illusory arm lengthening was induced while the arm was in contact with another body part such as the nose, interestingly, participants reported feeling like their nose was getting longer – the Pinocchio illusion. Although healthy body representations may intuitively seem rigid and resistant to alterations, these findings demonstrate that somatic experiences are indeed continually shaped by incoming sensory experiences and can change in response to altered sensory cues.

1.2.2 Rubber hand illusion

In contrast to the somatic illusions discussed above, body ownership illusions provide examples of alerted somatic experiences in which non-bodily objects such as fake limbs or manipulated limbs are incorporated into one's body representation. One of the earliest forms of such an illusion demonstrated that participants mistake a plastic finger protruding from a cloth as their own finger, when the real finger was concealed from view several centimetres away (Tastevin, 1937). The rubber hand illusion (RHI; Botvinick & Cohen, 1998) provides an example of a more profound somatic alteration in which a fake rubber limb is felt to belong to oneself and therefore provides a means of scientifically exploring body ownership. This section therefore describes the RHI and processes underlying the formation of the illusion with the aim of illustrating how understanding the mechanisms underlying somatic illusions are useful in understanding distorted bodily experiences.

In this experimental set-up, when a fake rubber hand that is placed in a position congruent with the real hand (occluded from view) is stroked in synchrony with the real hand, participants often feel touch on the rubber hand and report the rubber hand to be a part of their body (see Figure 1.1) ten to fifteen seconds later. Additionally, when asked to locate the position of the unseen real hand with the un-manipulated hand, proprioceptive responses are biased towards the position of the rubber hand thus suggesting that the fake hand has indeed been incorporated into the body representation.

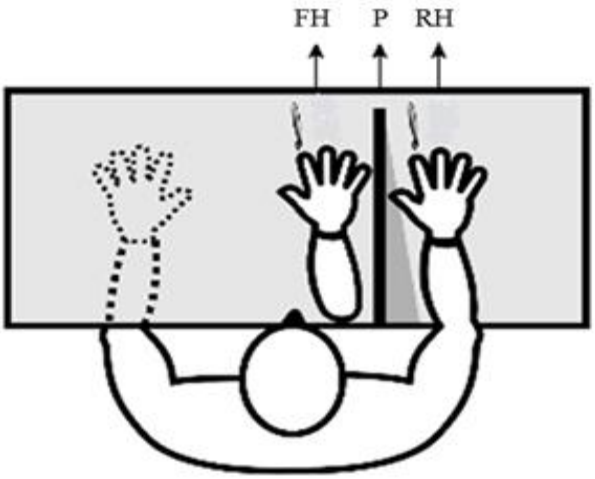


***Figure 1.1*:** Schematic diagram of the experimental setup in the Rubber hand illusion. RH= real hand, P= partition, FH= fake hand or rubber hand. (Taken from Capelari, Uribe & Brasil-Neto, 2009).

Neuropsychological studies have demonstrated that the feeling of ownership during the RHI is associated with activity in the premotor cortex – a brain area of multisensory representation (Ehrsson et al., 2004). Neurons in this region are involved in integrating visual, tactile and proprioceptive information (Grazinao, hu & Gross, 1997; Lloyd, Shore, Spence & Calvert, 2002) and have also been found to be anatomically connected to visual and somatosensory regions of the brain, thus reflecting the matching of both visual and somatic information during the illusion (Rizzolatti, Luppino & Matelli, 1998). In line with this idea, some patients with premotor cortex damage report an inability to recognise body parts or report body parts as 'missing' (Arzy et al., 2006a) indicating that damaged premotor regions may lead to disruptions in multisensory integration which in turn result in their altered states of self-awareness. Ehrsson et al. (2005) have found activity in similar brain regions in blind-folded participants as well, which demonstrates that activity in the premotor regions during the RHI does not merely

represent a visual object near the hands. Furthermore, reduced neuronal firing rates were observed in incongruent conditions that included a plastic brush instead of a rubber limb, suggesting that premotor cortex activity during the illusion is also dependent upon top-down knowledge of the seen object/hand. In addition to proprioceptive responses, ownership over the fake limb is supported by the observation that threatening the rubber hand leads to increased activity in brain areas associated with anxiety such as the left insula and the anterior cingulate gyrus (Ehrsson et al., 2007) as well as increased autonomic responses (measured using SCR; Armel & Ramachandran, 2003). Furthermore, ownership over the fake limb has been associated with homeostatic changes in the real hand. Skin temperature has been found to decrease in the real hand as ownership is claimed over the fake rubber hand (Moseley et al., 2008a). Indeed this decrease in skin temperature of the real hand was positively associated with the vividness of the illusion (Moseley et al., 2008a). Significant correlations have also been reported between the magnitude of illusion strength assessed using questionnaire items, proprioceptive estimations of the real hand position (Longo, Schüür, Kammers, Tsakiris & Haggard, 2008b), neural activity in the premotor cortex (Ehrsson et al., 2004) as well as the drop in temperature over the real hand (Moseley et al., 2008a), thus providing evidence for associations between both subjective and objective measures of ownership.

a) Mechanisms of the RHI

The RHI depends on an interaction between sensory inputs including, vision, touch and proprioception. In this illusion, synchronous stimulation felt in one location and seen in another location leads to multisensory conflict. To resolve this conflict, vision – the dominant sense involved in localising spatial events (Shibuya, Takahashi &

Kitazawa, 2007) dominates touch (coming from the unseen real hand) and remaps the tactile inputs towards the proprioceptive position of the seen rubber hand. This essentially creates a feeling that touch is arising from the rubber hand and thus results in a feeling ownership towards the fake rubber hand (Botvinick & Cohen, 1998).

b) Processes modulating the RHI: Bottom-up and top-down approaches

Botvinick and Cohen (1998) put forward a bottom-up explanation for the occurrence of the RHI, and suggested that synchronous visuo-tactile stroking of the real and rubber hand was necessary to induce the illusion, as they found no evidence for the illusion when visuo-tactile stroking was asynchronous. A later study by Armel and Ramachandran (2003) supported this view and provided evidence suggesting that synchronous visuo-tactile information was both sufficient and necessary to induce the RHI. The authors found evidence for the RHI despite visual inconsistencies in terms of skin tone and hand size as long as the unseen real hand and rubber hand were stroked in synchrony. More interestingly, the illusion was still elicited even when the fake rubber hand was extended up to three feet, placed in an anatomically implausible position and when participants viewed a table being stimulated in synchrony with the real hand. Based on their findings the authors concluded that strong correlations between different sensory inputs are necessary and sufficient for body ownership. Indeed, intermodal matching has been found to be an essential pre-requisite for perception of one's own body as an entity separate from the external environment as well as for self-recognition and body ownership from the earliest stage of development (Rochat & Striano, 2000).

Evidence in support of this account has, however, been rather limited, as most studies following Armel and Ramachandran (2003) have failed to replicate such effects.

Tsakiris and Haggard (2005) found that while correlated visual and tactile information caused the illusion, the illusion was not elicited when the laterality and identity of the viewed hand were manipulated. In their study, rotating the rubber hand by 90˚ with respect to the real hand abolished the illusion. Additionally, replacing the rubber hand with a wooden stick also broke down the illusion, thus suggesting that top-down knowledge regarding congruent position and identity are necessary prerequisites for the RHI while mere correlation of visuo-tactile information (between the unseen real hand and rubber hand/neutral object) was not sufficient to elicit the illusion. In line with these findings other studies have highlighted the role played by pre-existing visual knowledge of the hand during the RHI. Tsakiris et al. (2008) found no evidence for the RHI when the fake limb was replaced by a neutral object such as a plastic spoon which was of similar length to the rubber hand while Haans, Ijsselsteijn and deKort (2008) found that an artificial rubber hand was more readily incorporated into the body representation compared to an object that did not closely resemble the shape of a hand. Furthermore, these authors also highlighted the importance of skin texture in eliciting the illusion, as strength of the illusion significantly decreased when texture of the fake hand did not resemble human skin even though the object closely resembled a hand.

Collectively, these findings highlight the roles played by information including synchronous visuo-tactile stimulation and pre-existing visual, anatomical and postural features relating to the body in eliciting ownership over a body part (Tsakiris & Haggard, 2005; Tsakiris et al., 2008). The next sections focus on further experimental distortions to the body representation, particularly; how incorporating altered representations of body size shapes somatic perceptions.

1.3 Modifying perceived shape and size of body representation and somatic perception

Many studies have demonstrated that artificially altering perceived body representation, in terms of its shape and size using various techniques such as virtual reality and immersive virtual reality has direct consequences on somatic perception and perception of the external environment. For example, following local anaesthesia of body parts, Gandevia and Phegan (1999) demonstrated altered perceptual effects by making participants select from a range of images the one that was most representative of their perceived body size. Cutaneous anaesthesia of the thumb in particular, resulted in large and rapid increases in perceived size. Bruno and Bertamini (2010) altered representation of the hand in a modified RHI task making it look smaller or larger than veridical size. Participants were asked to estimate the size of an object presented to the unstimulated left hand relative to a standard object presented on the stimulated right hand. The object was felt to be larger or smaller following exposure to enlarged and shrunken representations of the hand respectively. In line with these findings, Linkenauger, Witt and Proffitt (2011) found that following magnification of perceived hand size, the perceived size of non-magnified objects were felt to be smaller suggesting that the hand is used as a 'perceptual ruler' in haptic perception. In a further study, van der Hoort, Guterstam and Ehrsson (2011) induced full body illusions that ranged from a doll's body to a giant's body to examine how these experiences influenced object size and distance in participants. Ownership was claimed over the larger and smaller body representations and both were found to alter size and distance perception in the external world. In particular, experiencing the smaller body led to objects being perceived to be larger and farther away, while the larger body led to objects being perceived to be smaller and nearer.

Similar findings are also reported in virtual environments. Linkenauger, Leyrer, Bülthoff and Mohler (2013) found that size perception of objects in the virtual environment was scaled according to the perceived (virtual) body size. A decrease in perceived hand size resulted in an increase in the perceived size of objects. The authors further demonstrated these scaling effects to not be a result of mere size-contrast effects, as the effects were only apparent following alterations to own body size and not simply any body part in the environment. Using immersive virtual reality (IVR) Slater, Spanlang, Sanchez-Vives and Blanke (2010) induced a body transfer illusion in which male participants' own body was substituted by a virtual female body. Perspective, movement and touch were altered such that participants viewed the virtual body from first person perspective (1PP) or 3PP, received synchronous/asynchronous touches and viewed synchronous/asynchronous head movements. Greater ownership ratings were seen over the virtual body from a 1PP following exposure to synchronous touches while stronger physiological responses to aversive stress were also reported from the 1PP compared to a 3PP. Further extending this study, other studies have shown that virtual bodies in the 1PP could substitute participants' own body, even in instances in which only certain body parts were distorted (*e.g.*, increased belly size) following synchronous visuotactile stimulation (Normand, Giannopoulos, Spanlang & Slater, 2011). Furthermore, Banakou, Groten, and Slater (2013) investigated a similar concept using IVR in which participants were given the experience that they embodied the body of a child or of a scaled down adult. As in previous studies, a strong sense of ownership was seen for both body forms; however, embodiment of the child's body led to significantly greater overestimations of object size and faster reaction times when ascribing child-like attributes to the self. Collectively

these studies suggest that somatic perception is malleable and that ownership can be claimed over distorted or altered body forms. In addition to shaping perception of our surrounding environment, such distorted body representations have also been found to alter the perception of pain.

Moseley et al. (2008b) found that magnifying or minifying the limb during movement altered pain perception in patients with complex regional pain syndrome (CRPS). The increase in pain ratings following movement was higher following visual magnification of the body part compared to minification. Patients with CRPS usually report excessive swelling of the affected body part and believe that the painful body part is larger than it really is (Peltz et al., 2011). As a result, magnification may have caused more swelling compared to minification resulting in the observed effects. In line with these findings, Ramachandran, Brang, and McGeoch (2009) used mirror visual feedback to shrink or magnify the phantom limb in a patient. They found that shrinking the phantom resulted in an immediate drop in pain. This reduction in pain further improved with increased minification; however, no difference in pain levels were seen when the viewed size of the hand was magnified while the pain returned if the patient had no vision of the hand or the lens was removed. Indeed, there is anecdotal evidence suggesting that viewing a limb through a minifying lens reduces ownership (Ramachandran & Ramachandra, 2007); hence, the effects observed by Ramachandran et al. (2009) may have been a result of reduced ownership of the phantom. Preston and Newport (2011) reported a reduction in pain levels for osteoarthritis, following illusory stretching and shrinking of the painful part of the limbs. The authors suggest that similar to other chronic pain states (*e.g.,* CRPS), osteoarthritis is also characterised by distorted body

representations; pain relief may have therefore resulted from the illusions correcting these distortions, or perhaps as a result of disownership of the body part as a result of its abnormal appearance. Pain relief following somatic manipulations is also observed for acute pain. An experimental study that examined contact heat-pain thresholds in a group of healthy volunteers found visual enlargement to increase analgesic effects, thus increasing heat pain thresholds and visual shrinking to reduce analgesic effects (Mancini, Longo, Kammers & Haggard, 2011). These findings also demonstrate manipulations of perceived body size to have different effects on chronic and acute pain. Such a difference could perhaps be due to different neural mechanisms underlying chronic and acute pain (Moseley, Sim, Henry, & Souvlis, 2005). In line with this, different therapies have proved useful in pain relief for the two pain states (Chou & Huffman, 2007) and more importantly chronic pain states have been found to alter the somatic representation of the affected body site (Maihöfner, Handwerker, Neundörfer & Birklein, 2003; Peltz et al., 2011). Therefore, in addition to shaping perception of objects and people in the environment, size altering somatic manipulations also alter pain, implying that such manipulations may be of clinical importance.

1.3.1 Inconsistencies in previous research

While the studies discussed above highlight the flexibility of the body representation, some studies have failed to find alterations in somatic perception following manipulations of body shape and size. This creates a need to more closely inspect and further understand the mechanisms underlying the varied effects of such somatic illusions/manipulations. For example, in a modified version of the RHI, Pavani and Zampini (2007) used a video camera to provide participants with veridical and

visually enlarged or shrunken representations of their own hand. Significant effects of the illusion as measured by proprioceptive drift (*i.e.*, pointing to perceived location of the stimulated hand with unstimulated hand) was only found following exposure to the veridical and enlarged representations of the hand. Based on their findings the authors suggested that specific top-down information relating to the body, in this case its size plays an important role in modulating the illusion. In a later study, Haggard and Jundi (2009) elicited the RHI using gloves that were smaller or larger than participants' veridical hand size to examine its effects on weight perception. Participants reported the weight of equal sized cylinders that had different masses. Proprioceptive drift towards the felt position of the real hand was also measured. While no effects of hand size were seen for judgments of proprioceptive drift, participants significantly overestimated weight of the cylinder with the large glove however no significant differences in perceived weight was seen with the smaller glove. In line with these findings, illusory arm extension following tendon vibration (Lackner, 1988) led to better tactile acuity in two-point discrimination tasks, however, no such change was seen following illusory shrinking of the forearm (de Vignemont, Ehrsson & Haggard, 2005). Collectively these findings indicate that illusions of increased body size are much stronger. This could perhaps be due to illusions of body enlargement/elongation being in the direction of growth – which is frequent and rapid as opposed to minification/shrinkage - which is restricted to slow changes seen in old age and/or following traumatic amputation (Haggard & Jundi, 2009). There is also anecdotal evidence suggesting that viewing minified limbs reduces ownership over the limb (Ramachandran & Ramachandran, 2007) which seems plausible given the asymmetric flexibility of body representations towards body parts that are

larger than normal. It should however be noted that these previous studies did not allow dynamic changes in body size and the depictions of the body parts viewed by the participants were constrained in movement. Such representations are therefore, less realistic in appearance and lack ecological validity. Given our reduced exposure and experience with shrunken body parts (due to slow and small changes in old age, or limb amputation following traumatic accidents), such representations may have been less likely to be incorporated into one's body representation. Indeed, emotion recognition literature has suggested that emotions are better recognised and rated to be more realistic and intense with dynamic stimuli compared to static stimuli in both healthy and patient populations (Harwood, Hall & Shinkfield, 1999; Weyers, Mühlberger, Hefele & Pauli, 2006). Additionally, studies have also revealed greater activity in the visual and temporal cortices following exposure to dynamic compared to static stimuli (Kilts, Egan, Gideon, Ely, & Hoffman, 2003) perhaps due to greater availability of information in dynamic displays.

1.4 MIRAGE (Please refer to Chapter 3 for detailed description)

The MIRAGE mediated reality device (The University of Nottingham; Newport, Preston, Pearce & Holton, 2009) uses novel technology to create spatially coincident dynamic illusions. Participants' own body parts can be manipulated in real time giving rise to realistic illusions that range from alterations in perceived body size to illusions that alter postural configurations. For example, in the size altering illusion, participants watch their body parts increase or decrease in size simultaneously as the experimenter pulls or pushes the body part. The system therefore provides congruent visual, tactile and

proprioceptive information thus creating convincing alterations in the body representation.

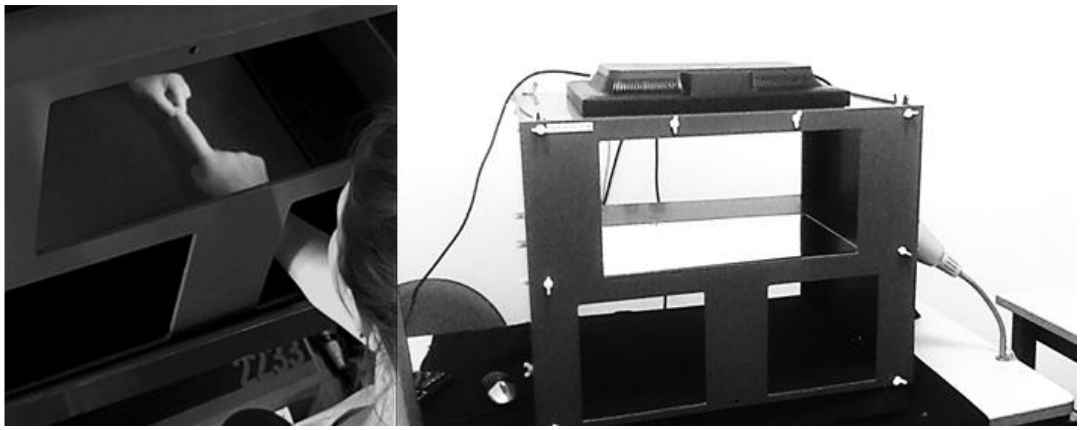


Figure 1.2: The MIRAGE mediated reality system

The following section discusses a range of empirical investigations conducted using the MIRAGE mediated reality system. The section aims to highlight the scope of the MIRAGE mediated reality system in its ability to alter somatic experiences to further understand the mechanisms underlying altered somatic states and the malleability of the body representation.

1.4.1 Studies that used the MIRAGE mediated reality device

The MIRAGE system allows the experimenter to manipulate features and events of the body to more closely investigate altered somatic representations, ownership and embodiment in both healthy and clinical populations. In this way the system provides a means of further examining the mechanism and factors contributing to distorted somatic experiences.

While previous studies have shown the RHI to resist the body schema – a dynamic representation of the body involved with posture and motor actions (Paillard, 1999; Kammers, de Vignemont, Verhagen & Dijkerman, 2009), Newport et al. (2010) argued that the static nature of the rubber hand in traditional RHI studies may have prevented its incorporation into the body schema. Using the MIRAGE mediated reality system, Newport et al. (2010) simultaneously presented participants with two dynamic representations of their own hand under three conditions; (1) hand on the left synchronously stroking a toothbrush (with delay on the right), (2) hand on right synchronously stroking a toothbrush (delay on the left) and (3) both hands synchronously/asynchronously stroking a toothbrush. Results indicated that during the left and right synchronous conditions, ownership was claimed over the hand on the left and the hand on the right respectively. Interestingly during the both synchronous condition, ownership was claimed over both hands. When asked to point to a target, hand paths were more rightward in the left synchronous condition and vice-versa during the right synchronous condition. During the both synchronous condition, participants made reaching movements in the presence and absence of virtual distractors and no differences in hand paths were observed between the two conditions. A difference in hand path judgements would have suggested that both representations of the hand were simultaneously incorporated into the body schema, however, the absence of this difference suggests that the distractors were not avoided resulting in one of the hand representations passing through a distractor. Results of this study therefore, extended previous studies by providing evidence for two dissociable body representations; the body image (internal mental representation of the body; Paillard, 1999) and also body

schema and highlighted the flexibility of both. The novel finding was that following synchronous visuotactile input, dynamic limbs can be incorporated into the body schema. Furthermore, while the body image was seen to accommodate multiple representations a limb, only a single representation of a limb could be incorporated into the body schema.

Although the previous study provided evidence for multiple fake limbs to be incorporated into the body representation, it is as yet unclear whether the real limb is disembodied under such circumstances. Previous studies have provided mixed evidence in this regard. On the one hand some studies have reported ownership over the fake hand to be associated with a temperature drop in the real hand, thus indicating disownership of the real hand (Moseley et al., 2008a). Others have found similar somatosensory response patters during the RHI and also when a proprioceptive mismatch between the seen and felt position of the real hand was induced using prism goggles. This indicates that alterations in somatosensory processing during the RHI may not be a result of disownership of the real hand but rather a cross-modal mismatch (Folegatti, de Vignemont, Pavani, Rossetti & Farnè, 2009). Using the MIRAGE mediated reality system Newport and Preston (2011) provided participants with two video images of their own hand; one in the real location of the hand (real hand) and one slightly offset (fake hand). Temporal synchrony was altered with a delay of 0.5 seconds applied to one of the hands. Subjective and objective measures of ownership obtained using ownership statements and SCR respectively indicated that the real hand was disowned and ownership was claimed over the fake hand when it was synchronous. In contrast, only mild differences were found for reaching judgements, suggesting that while the real limb

was disembodied from the body image, it may not have been completely disembodied from the body schema.

While limb disembodiment in previous experimental studies have only been seen when an alternative body part was embodied, clinical studies are not always consistent with this observation. For instance, patients with somatoparaphrenia lose awareness of a body part; however, do not embody alternative body representations. Newport and Gilpin (2011) created an illusion in which participants' right hand disappeared from sight and touch when they reached for it with their left hand. Participants instantly reported that their hand was no longer a part of their body and lost sensation of the hand. SCR revealed no physiological response to the disappeared hand when it was threatened compared to control conditions. Furthermore, self-drawn representations of the disappeared hand illustrating participants' experience of their arm were incomplete and terminated at the wrist. The illusion resulted in no visual and tactile information of the hand and repositioned proprioceptive information, therefore, it could be argued that disembodiment and disownership of the (disappeared) limb resulted from distorted bottom-up sensory information relating to the limb. The study thus provides important insight into the mechanisms responsible for deficits seen in somatoparaphrenia and asomatognosia.

When examining ownership and embodiment over body parts, it is also important to explore factors and processes that prevent embodiment. Preston and Newport (2011a) examined whether violating the physical space around the hand resulted in limb disembodiment and disownership. Using the MIRAGE system, they presented participants with two synchronous images of their own hand – one closer to and one further away from the body midline. Participants stroked a sponge tipped stick for 20

seconds, after which the stick was seen to move through either one of the hands. Questionnaire data revealed that encroachment was only found to disrupt ownership for the limb furthest from the body midline. Pointing responses were also in the same direction, such that when the far hand was encroached, participants pointed as though the position of their hand shifted towards the near hand (that was not encroached) thus suggesting that both body schema and body image were similarly affected by violations to the space around the body. Findings of this study highlight the importance of distance from the body midline in maintaining ownership and embodiment and expand previous RHI studies that have found strength of the illusion to diminish as the distance of the fake hand was increased (Lloyd, 2007; Costantini & Haggard, 2007). In a further experiment Newport and Preston (2011) examined how perceived continuity of a body part influenced ownership, embodiment and agency – *i.e.*, sense that we are in charge/control of our actions. Participants were given the impression that the tip of their index finger was pulled until it was detached from the rest of the finger – the stump. Whether or not the detached tip was under participants' control was also manipulated. The authors then examined SCR to threat when either the detached tip or the stump was stabbed with a virtual weapon. Reduced SCR were observed when the tip was detached regardless of whether or not the detached tip was under participants' control. Disrupting control over the finger, when the finger was fully intact also led to reduced SCR. High responses to perceived threat was apparent only in a condition in which the finger was intact and remained under participants' control. This highlights the importance of both perceived agency and continuity of a body part in maintaining ownership and embodiment. Finally,

no differences were seen between stabbing the tip and the stump, thus indicating that discontinuity led to disownership of not just the tip but the entire hand.

In addition to providing a means of investigating factors responsible for maintaining a stable body representation and processes responsible for breaking down ownership and embodiment, illusions developed using the MIRAGE system have also been found to be clinically applicable in providing temporary relief in patients with osteoarthritis. Preston and Newport (2011b) found that visuo-proprioceptive stretching and shrinking of the painful area of the body alleviated pain. The authors suggested that their findings are consistent with the idea that osteoarthritis pain results from distorted body representations in such patients (Haigh, McCabe, Halligan & Blake, 2003), which may have been corrected following illusory enlargement and shrinking of the body part. A later study by Gilpin, Moseley, Stanton and Newport (2014) examined whether patients with painful osteoarthritis have distorted body representations. Participants were presented with images of their own hand and were instructed to manipulate it in real time until it felt to be the size of their real hand. Interestingly, the osteoarthritis group judged smaller representations of their hand to be normal, indicating that these patients hold distorted representations of their body. These findings may therefore strengthen previous explanations by Preston and Newport (2011b) – suggesting that pain relief may have resulted from normalising the distorted mental representations of the painful body part.

In a recent study, McKenzie and Newport (2015) altered the visual appearance of participants' hand to give it a static appearance – the crawling skin illusion. The illusion was expected to create somatic sensations in the absence of any real somatosensory input. The authors examined the influence of this illusion on individuals with increased and

decreased tendencies towards misperceiving benign somatic sensations. Interestingly, questionnaire items examining the effects of the illusion indicated that those with a greater propensity to misperceive bodily events reported more somatic sensations. These individuals also reported reduced ownership over the limb compared to controls. The authors discussed their findings in relation to theories proposing increased somatic awareness (Rief & Barsky, 2005) and greater top-down reliance in such individuals (Brown, 2004).

The studies discussed in this section therefore suggest that the MIRAGE mediated reality system could be used to administer a range of somatic manipulations. The system has been useful in devising controlled experimental paradigms that have further improved the understanding of the mechanisms underlying somatic distortions such as misperceived bodily sensations and self-awareness including the mechanisms/conditions underlying body ownership and disownership thus providing evidence for the dynamic flexibility of the body representation.

1.5 Summary: Misperceptions, somatic illusions and the MIRAGE system

Misperceptions of the body, similar to those experienced in clinical populations can be experimentally examined through the use of experimentally induced somatic illusions (*e.g.*, RHI). Although such illusions have provided a means of investigating distorted somatic experiences in healthy participants, the limited ecological validity in traditional experimental set-ups have resulted in inconsistent findings of somatic perception (Pavani et al., 2007; Haggard & Jundi, 2009). Through the use of realistic and dynamic manipulations of the body representation, the MIRAGE mediated reality system

addresses limitations of traditional experiments and has provided a means of systematically examining distortions in somatic perception. While Chapter 1 provided an overview of the conditions under which perceived body representation is altered as well as how such experiences alter subsequent body perception, Chapter 2 aims to focus on the conditions that alter somatosensation – particularly how illusory somatic manipulations (in line with those discussed in Chapter 1) may alter what we feel on the body and related individual differences in participants' response patterns.

CHAPTER 2

GENERAL INTRODUCTION (ii)

This chapter discusses the conditions under which somatosensation can be experimentally manipulated and aims to provide an overview of an experimental task that enables the investigation of the mechanisms underlying altered somatic sensations. Chapter 2 also provides an overview of individual differences in responsiveness and susceptibility to somatic illusions and somatosensation.

2.1 Cross-modal integration

While vision is deemed the dominant sense that plays a significant role in shaping perception of the world, Shams, Kamitani and Shimojo (2000) have provided evidence that an auditory stimulus can alter perception of a visual stimulus. The authors found that when a single uniform light was accompanied by multiple auditory beeps, participants incorrectly perceived the single flash as multiple flashes. The auditory stimuli had no effect when multiple visual stimuli were presented; indicating that this effect was selective, and that continuous stimuli in one sensory modality is perhaps more malleable to discontinuous stimuli in a different sensory modality. In line with this interaction, auditory stimuli have also previously been found to enhance the perceived intensity of a light emitting diode (LED; Stein, London, Wilkinson & Prince, 1996). Moreover, in a series of experiments investigating auditory and tactile integration, Gillmeister and Eimer (2007) showed that simultaneously presented task-irrelevant tactile stimuli not only improved detectability of weak auditory stimuli, but also enhanced the perceived loudness of the auditory stimulus. Further extending studies by Shams et al. (2000) and

Stein et al. (1996) task irrelevant visual stimuli have been found to alter perception of weak auditory stimuli. Lovelace, Stein and Wallace (2003) had participants indicate the presence or absence a weak sound that was either presented alone or in conjunction with a task irrelevant visual stimulus. Correct detections of auditory stimuli (when one was present) were increased in the presence of the light, leading to more hits. Similarly, the light also increased perception of the sound when none was present, leading to false sound detections or false-alarms. The authors then used signal detection theory analyses (MacMillan and Creelman, 1991) to examine whether the light altered sensitivity to the tactile stimulus and improved participants' ability to discern between sound present/absent trials or simply led to a bias to positively report the sound regardless of whether or not one was present - (*i.e.,* increased 'yes' responses). Results indicated that participants' responses were driven by both enhanced detection of sound and response bias. In a further study designed to eliminate the effect of response bias, the authors separated light present and light absent trials into different blocks. Here, the light improved detection of the sound in the absence of any shifts in response bias, suggesting lower-level multisensory mechanisms to be operating within the observed visual-auditory interactions (Lovelace et al., 2003). In a similar study that involved detection of tactile target stimuli in the presence and absence of a task irrelevant visual stimulus, the simultaneous visual stimulus again increased both hits and false-alarms (Johnson, Burton & Ro, 2006). Using signal detection analyses the authors demonstrated the improved tactile reports in the presence of the light to be attributed to liberal response criterions as well as to increased perceptual sensitivity (the ability to correctly discern stimulus present from stimulus absent trials). In a modified version of this experiment called the Somatic

Signal Detection Task (SSDT; Lloyd, Mason, Brown & Poliakoff, 2008) participants were asked to report the presence or absence of a near-threshold tactile stimulus presented on 50% of trials, regardless of whether or not it was accompanied by a task irrelevant light. In line with findings of Lovelace et al. (2003) and Johnson et al. (2006), the task irrelevant light altered response criterion, leading to increased reports of tactile perception both when tactile stimuli were present and absent resulting in increased hits and false-alarms respectively. Liberal response criterions were again found to drive the increase in light present hits and false-alarms; however, this original SSDT study did not find an increase in tactile sensitivity (or participants' ability to correctly discern between stimulus present and absent trials). Subsequent studies using the SSDT however, found improved tactile sensitivity in the presence of the light (Mirams, Poliakoff, Brown & Lloyd, 2010; McKenzie, Poliakoff, Brown & Lloyd, 2010) and such an effect may be due to improved statistical power (in later studies) as a result of employing more participants (c.f. Mirams et al., 2010).

These findings provide collective evidence that a task-irrelevant stimulus in one modality can influence the perception of target stimuli of a different modality, leading to increased correct and incorrect target-stimuli detections as a result of both increased sensitivity and liberal response biases. The incorrect touch reports in these studies suggest that task irrelevant visual stimuli lead to illusory auditory (Lovelace et al., 2003) or tactile (Johnson et al., et al., 2006; Lloyd et al., 2008) perceptions in another sensory modality. While correct target detections or hits may suggest multisensory enhancement effects whereby spatially and temporarily coincident sensory signals are perceived as a single event, different processes are expected to operate for false-alarms which are

unisensory by nature. Given the lifelong exposure one has with correlated sensory inputs (*e.g.*, vision and touch); false-alarms may reflect a bias towards perceiving tactile/auditory inputs even in the absence of any, as a result of prior multisensory experiences (Johnson et al., 2006).

Psychophysical and neuroimaging studies have provided evidence for these cross-modal facilitative effects. Diederich and Colonius (2004) compared reaction times to unimodal, bimodal and trimodal visual, auditory and tactile stimuli combinations. Faster reaction times to simultaneously presented trimodal stimuli were seen as compared to bimodal stimuli which were in turn faster than their constituent unimodal inputs. Here again evidence for integrated multisensory processing were seen as the responses to multisensory stimuli were far greater than the summation of unimodal stimuli. In line with these studies, Murray et al. (2005) found participants to more rapidly detect combined audio-somatosensory stimuli compared the individual unisensory events. Using electroencephalography (EEG) these authors also found neural responses to multisensory events to be greater than for the summed unisensory events as early as 50 ms post stimulus. Furthermore, an early single unit recording study by Meredith and Stein (1986) found increased neural activity when visual and auditory stimuli were presented in conjunction compared to when they were presented separately. Intriguingly, the increase in neural activity was greater than the sum of the response amplitudes evoked by each stimulus (visual or auditory) alone, and was even higher when visual and auditory stimuli were spatially coincident.

In sum, this section provides evidence suggesting that presenting stimuli in more than one modality results in it being perceived faster and with greater accuracy than when

presented separately. The next section further discusses multisensory interactions however, focuses specifically on visual and tactile integration.

2.2 Visuotactile interactions

Many investigations have provided evidence for the role of vision in altering somatosensation, even in instances in which vision is non-informative – that is, when the visual stimulus (*e.g.*, light) does not signal whether a tactile stimulus would be delivered. Kennett, Taylor-Clarke and Haggard (2001) examined tactile two-point discrimination thresholds when visibility of the arm was manipulated. In this task participants had to discriminate between one or two simultaneously presented tactile stimuli that were spatially separated. Discrimination thresholds were better when vision of the hand was available, compared to when the hand was in complete darkness or replaced by a neutral object, indicating improved tactile acuity. Indeed, a control study revealed no performance benefits when participants watched a replay of the hand in the absence of any tactile stimulation, suggesting that no information of touch was provided when the arm was visible. Taylor-Clarke, Kennett and Haggard (2002) provided evidence for a neural basis for this enhancement effect of vision. In their study, vision of the hand was found to alter somatosensory cortex activity as demonstrated by somatosensory event related potentials (ERP). The authors suggest that visuo-tactile bimodal neurons in the parietal regions (previously been found to be associated with integrating visual and tactile information; Iriki Tanaka & Iwamura, 1996; Burton et al., 1999; Ehrsson, Spence & Passingham, 2004; Lloyd, Shore, Spence & Calvert, 2003) may have modulated somatosensory cortex activity, resulting in the observed enhancement effects.

Interestingly, the presence/absence of vision has also been found to alter illusory touch sensations (false-alarms). In a study by Mirams et al. (2010) participants reported the presence or absence of tactile stimuli on the Somatic Signal Detection Task (SSDT) in conditions where non-informative vision or no vision of the hand was available. Increased illusory touch reports were reported in the presence of the task irrelevant light when vision of the hand was available compared to the no vision condition. In contrast to previous studies, vision did not alter correct touch detections (Kennett et al., 2001; Taylor-Clarke et al., 2002) or signal detection test statistics, tactile sensitivity (*d'*) and response criterion (*c*). The task irrelevant light (in the SSDT) may have therefore resulted in a tactile attentional shift, leading to increased illusory touch reports, however, this shift would have been stronger when non-informative vision of the hand was present perhaps due to increased activation of bimodal visuo-tactile neurons during this condition (Mackay & Crammond, 1987; Graziano, Yap & Gross, 1994). Indeed, Harris, Arabzadeh, Moore and Clifford (2007) found non-informative vision to improve performance on tactile discrimination tasks in which participants were presented with two vibrations in consecutive intervals and asked to judge the vibration with the stronger amplitude. Performance was impaired on simple tactile detection tasks in which participants judged the interval (first or second) that contained the vibration. Non-informative vision therefore does not have a general facilitative effect on somatosensory processing but has differential effects depending on the type of tactile measure involved. Further extending these studies Longo and Sadibolova (2013) examined how vision affects somatosensation. In that study, participants reported the perceived distance between two simultaneous tactile points that were 20 mm, 30mm or 40mm apart. Tactile distances

were perceived to be significantly smaller when participants viewed the stimulated hand compared to when they viewed an object or the contralateral hand. Vision therefore distorts touch by altering its metric properties.

2.2.2 Manipulating perceived body size and tactile perception

While vision of the hand was previously found to enhance tactile acuity, this effect has been found to be further improved when the viewed hand was magnified, evincing even lower two-point discrimination thresholds (Kennett et al., 2001) and thus suggesting that manipulating the (visual) body representation further alters somatosensation. Taylor-Clarke, Jacobsen and Haggard (2004) showed that while perceived distance between two simultaneous tactile contacts felt larger on the finger than forearm on 81% of the trials, this bias significantly reduced (from 81% to 74%) when participants viewed their forearm enlarged and finger size reduced. de Vignemont, Ehrsson and Haggard (2005) examined the link between proprioception and touch following illusory finger extension and shrinkage induced by biceps and triceps tendon vibration respectively (Lackner, 1988). When asked to compare the perceived distance between two simultaneous tactile contacts placed on the finger, perceived distance felt bigger following illusory elongation compared to a control condition with no illusion, although no difference was observed between an illusory shrinking and control condition. Further extending this study, D'Amour, Pritchett, and Harris (2015) examined both tactile acuity and tactile sensitivity by comparing performance on a task that required participants to indicate the interval (1st or 2nd) in which two simultaneous tactile stimuli were presented, and a task that required detecting the interval (1st or 2nd) containing the tactile stimulus respectively. Arm and waist size were altered during each task using the

tendon vibration illusion (Lackner, 1988; de Vignemont et al., 2005). In contrast to the findings by de Vignemont et al. (2005) both tactile acuity and sensitivity was influenced by the illusion conditions compared to a control condition, suggesting that the body site that to which manipulations are applied may have different effects on tactile outcomes. The studies discussed thus far therefore suggest that both visual and proprioceptive alterations of body size can alter the perception of tactile stimuli.

In addition to the effects on tactile perception, as discussed in Chapter 1, manipulating perceived body representation has also been found to alter haptic judgements (Bruno & Bertamini, 2010), pain perception (Moseley, Parsons, & Spence, 2008; Mancini, Longo, Kammers, & Haggard, 2011; Preston & Newport, 2011) as well as perception of objects in the external environment (van der Hoort, Guterstam, & Ehrsson, 2011). Taken together the studies listed in this section suggest that while vision of the body alters somatosensation in terms of reaction time to tactile stimuli, tactile acuity and metric properties of touch, manipulating the visual and proprioceptive information relating to the stimulated body part further improves or reduces such effects thus providing a link between perceived body representation and somatosensation.

2.2.3 Summary of vision and manipulated body representations on somatosensation

While vision of the body has been found to alter somatosensation visual and proprioceptive alterations to the body representation further modulates this effect by increasing or decreasing tactile sensitivity and tactile acuity (Kennett et al., 2001; de Vignemont et al., 2005; D'Amour et al., 2015). Although, the mechanisms underlying visuo-tactile integration have been investigated (Lovelace et al., 2003; Johnson et al., 2006; Lloyd et al., 2008), thus far few studies have examined the mechanisms responsible

for altered somatosensation following illusory alterations of perceived body size. It is unclear whether the observed effects of previous studies are a result of alterations of one's perceptual sensitivity or purely influences of response bias (Kennett et al., 2001; de Vignemont et al., 2005). Somatosensation has most commonly been examined using tactile detection tasks (Kennett et al., 2001; de Vignemont et al., 2005; Lloyd et al., 2008; Longo & Sadibolova, 2013). However, tactile stimuli used in most previous studies have also been above threshold, and tactile intensity was not individually set for each participant, therefore, such stimuli may have served as reliable indicators of touch, especially in forced choice tasks that required participants to determine the interval (1st or 2nd) in which the stimulus was presented. In terms of the effect of altered body representations on somatosensation, most early studies (Kennett et al., 2001; Taylor-Clarke et al., 2004) have either been limited to a perceived visual enlargement of body parts or have failed to find significant differences in somatosensation following exposure to shrunken body parts (de Vignemont et al., 2005). Additionally, Longo and Sadibolova (2013) failed to find any alterations to metric properties of touch following manipulations of body shape and size. Closer inspection of the influence altered body representations on somatosensation (with better control) is therefore required.

2.3 The Somatic Signal Detection Task (SSDT; Lloyd et al., 2008)

The SSDT (Lloyd et al., 2008) requires detection of near-threshold tactile stimuli that are presented at an intensity level determined individually for each participant, via a staircase thresholding procedure (Cornsweet, 1962). The tactile stimuli may or may not be accompanied by a task irrelevant light, and the task of the participant is to report

whether or not they felt a tactile stimulus on each trial. Using signal detection theory (Macmillan and Creelman, 1991) this task provides a means of examining whether correct and incorrect tactile detections (*i.e.*, hit rates and false-alarm rates respectively) are driven by tactile sensitivity (*d'*) – ability to discern tactile present from tactile absent trails or response bias (*c*) – tendency to positively report feeling the tactile stimuli regardless of whether or not one was present. The SSDT therefore serves as a valuable tool for investigating the mechanisms underlying alterations to somatic perception under conditions of altered visual experience and manipulated body representations.

2.3.1 Studies using the SSDT

The SSDT was developed by Lloyd et al. (2008). When asked to judge the presence or absence of a near threshold tactile stimulus (presented 50% of the time), increased hit rates and false-alarm rates were reported when the tactile stimulus was accompanied by a task irrelevant light. These increases were accompanied by reduced response criterions, indicating that participants were more likely to say 'yes' in the presence of the light. Therefore, the task irrelevant visual stimulus may have reduced the uncertainty associated with detecting the near threshold tactile stimulus by increasing tactile attention to the hand or by creating a tactile representation in memory. In this sense, the visual stimulus may have exerted a top-down influence on tactile perception on the SSDT (Lloyd et al., 2008). McKenzie et al. (2010) examined individual differences in illusory tactile experiences or false-alarms on the SSDT. In two experiments they studied the tendency to report illusory touch experiences in two testing sessions that were a week apart, and then three testing sessions that were up to one month apart. Illusory touch reports in both studies were found to correlate and were accompanied by alterations in

response bias which were also found to be positively correlated across both sessions. The tendency to experience illusory tactile experiences is therefore stable over time and is influenced by participant's bias to positively report feeling somatic sensations regardless of whether or not any stimulus was actually present. In the study by Lloyd et al. (2008) the same LED served as both the task irrelevant light and the start cue. It could therefore be argued that attention may have been drawn to the location and modality of the LED resulting in the observed increase in hit and false-alarm rates. Therefore, as a secondary aim, McKenzie et al. (2010) also compared the effect of start cue modality using auditory and visual start cues. No difference in performance was observed, suggesting that the visual start cue did not impact performance by drawing attention to the task irrelevant light. Given that both visual and auditory cues are orthogonal to the target modality – touch, a tactile start cue would perhaps more significantly impact performance. The authors also examined this by comparing a tactile start cue to a visual start cue and again found no significant difference between the two, providing evidence for false-alarms independent of stimulus-priming effects (McKenzie et al., 2010).

While the increased correct touch reports or hit rates in the presence of the light indicates that the light may have facilitated tactile detection, the same principle does not apply to false-alarms as such trials are unimodal and consist of only a single stimulus – the visual stimulus. Improved detection of target stimuli that are accompanied by simultaneous stimuli from an orthogonal modality is thought to reflect prior experience in integrating correlated multisensory information (Johnson et al., 2006). False-alarms or illusory touch experiences induced by light could therefore be a result of such a tendency to integrate sensory information – in this case vision and touch. Conversely, it could be

argued that false-alarms are a result of a light-touch association or ‘illusory correlation’ (Chapman, 1967) built up during the course of the experiment as bimodal and unimodal trails are interspersed during the SSDT. McKenzie, Lloyd, Brown, Plummer and Poliakoff (2012) examined the effects of exposure to bimodal visuo-tactile stimuli on tendencies to report false-alarms. Participants responded to blocks of trials consisting of unimodal stimuli, followed by bimodal stimuli and finally unimodal stimuli again. Interestingly, false-alarms were reported in the first block despite participants receiving no bimodal stimuli and no difference in false-alarm rates was observed between blocks even though bimodal stimuli were introduced in the middle. Visually induced false-alarms on the SSDT are therefore not an artefact of the experimental procedure but instead reflect a general tendency to integrate multisensory information that is spatially and temporally coincident. In this sense, the task irrelevant visual stimulus would have been used to resolve the ambiguity of the degraded tactile stimulus, even in the absence of any tactile input. Next, the authors examined whether prior experience with strongly or weakly associated visuo-tactile stimuli would alter light induced false-alarms. Participants trained with low light and touch pairings reported significantly fewer false-alarms in both the presence and absence of light, however, no change in false-alarms were seen in participants trained with strong light-touch parings. Given that the influence of the light is dependent upon an association between vision and touch that occurs throughout one’s life (Johnson et al., 2006); this learning effect may have already been at ceiling resulting in the latter finding (McKenzie et al., 2012).

Lloyd, McKenzie, Brown and Poliakoff (2011) examined the neural correlates of false-alarms on the SSDT. Using fMRI the authors examined the blood oxygenation

level-dependent (BOLD) response to both light present and absent illusory tactile experiences. Both light present and light absent false-alarms were found to show improved activity in top-down regions such as the medial parietal cortex including posterior cingulate cortex (PCC) and the precuneus (PCu), the primary and secondary visual cortices as well as the medial prefrontal cortex (mPFC). These findings suggest similar underlying mechanisms for both light present and absent false-alarms and extend previous studies that have suggested false-alarms to reflect top-down effects on the perception of ambiguous tactile stimuli.

Simple perceptual factors have been found to alter performance on the SSDT. Mirams, et al. (2010) compared response patterns when participants responded to touch in the absence of vision (but the task irrelevant light still seen) or in the presence of non-informative vision. Only light present false-alarm rates were found to be influenced by the availability of vision and were found to be significantly higher when vision of the hand was available compared to the no vision condition. The effects of vision on tactile perception is mediated by visuo-tactile bimodal neurons in the parietal regions (Lloyd et al., 2003) which are found to be less active when vision of the hand is prevented (Graziano, Yap and Gross, 1994). In the case of this study, the task irrelevant light may have led to a stronger shift in tactile attention during the vision condition (compared to the no vision condition) resulting in increased activity of bimodal neurons. Additionally, it is also possible that increased attention to the hand (as a result of the light) may have brought to awareness previously unperceived subtle internal bodily sensations, such as pulse sensations in the finger, which may have interfered with detection of the near threshold tactile stimulus – leading to increased misperceptions and in this case false-

alarms. Mirams, Poliakoff Brown and Lloyd (2012) then investigated the effects of internal somatic sensations on tactile perception on the SSDT. The study directly compared the effects of interoception (internal somatic sensations) and exteroception (perception of external tactile sensations). SSDT response patterns following a heartbeat perception task aimed at increasing interoceptive awareness and a grating orientation task aimed at increasing exteroception (during which time participants reported the perceived the orientation of a grating dome applied on their finger) were compared. While the first task led to liberal response criterions and increased false-alarms, the latter led to more stringent response criterions. Therefore, while increased awareness of heartbeat sensations interfered with tactile perception by increasing internal somatosensations, the grating task may have reduced the interfering effects by diverting attention away from distracting stimuli. While Mirams et al. (2012) have shown that changing the nature of body focused attention, alters subsequent somatic perception, Mirams et al.(2013) examined whether changing the nature of interoceptive awareness would alter tactile perception on the SSDT. All participants initially performed the SSDT at baseline and then eight days later. Over the course of the eight days, half the participants listened to an eight minute body-scan mindfulness meditation recording while the other half listened to a recording of a story. In contrast to Mirams et al. (2012) participants who listened to the body-scan meditation recording reported fewer false-alarms and displayed improved tactile sensitivity. The effects of interoceptive awareness on tactile perception is therefore dependent upon the nature of attention directed to the body, as increased awareness of heartbeat/pulse sensations increases misperceptions, however, mindful mediation involving brief body-scans reduces such erroneous touch reports.

The studies discussed in this section have provided evidence to suggest that the SSDT is a valuable tool that provides insight into the mechanisms responsible for altered somatic sensations. Their findings also suggest that our somatic experiences do not always reflect reality and are often influenced by information from other sensory modalities and top-down factors, including prior experiences and attention. As a result, the occurrence of illusory touch reports or false-alarms on the SSDT, particularly in the presence of the task irrelevant light have been argued to closely mimic psychosomatic disorders (Lloyd et al., 2008) such as medically unexplained symptoms and is therefore useful in further examining such clinical misperceptions.

2.4 False-alarms on the SSDT as a laboratory analogue of unexplained physical symptoms

Physical or psychiatric symptoms with no identified cause or explanations are common across medical settings. The severity of these illnesses spans a continuum from patients with extremely mild and transient symptoms to those experiencing several debilitating symptoms (Brown, 2006) which may become increasingly distressing and disabling with time (Brown, 2004). A number of different terms including functional somatic symptoms (Trimble, 1982), somatisation (Kellner, 1985) and medically unexplained symptoms (Mayou, 1991) have been used to describe such unexplained symptoms, however, for clarity the phrase medically unexplained symptoms (MUS) will be used to throughout this thesis. Although the precise aetiology of MUS is poorly understood, recent theoretical models suggest that they could arise from the over-activation of symptom-representations in memory (Brown, 2004) or increased attention to the body, which could lead to the over perception of symptoms and benign bodily

events (Rief & Barsky, 2005; Deary, Chalder & Sharpe, 2007; Rief & Broadbent, 2007; Mirams et al., 2010).

During the SSDT, light present illusory touch experiences or false-alarms are thought to arise from the light either activating tactile representations in memory (Lloyd et al., 2008) or increased attention to the hand which increases interoceptive awareness (Lloyd et al., 2008; Mirams et al., 2010, 2012). Therefore, the task irrelevant light (although in no way is related to MUS) could be used to create unexplained somatic experiences under laboratory settings by mirroring the processes that may be responsible for the formation and maintenance of such symptoms (Lloyd et al., 2008).

Brown, Brunt, Poliakoff and Lloyd (2010) aimed to evaluate the theoretical predictions relating to the role of tactile perception in the development of MUS by determining the association between false-alarms and tendencies to experience MUS. Response patterns of participants with and without tendencies towards MUS as indicated by their scores on the somatoform dissociation questionnaire- 20 (SDQ-20; Nijenhuis, Spinhoven, Van Dyck, Van der Hart & Vanderlinden, 1996; Maaranen et al., 2005) were compared. False-alarm rates were found to be significantly higher for participants with increased tendencies toward MUS – an effect attributable to more liberal response criterions. This study therefore establishes the proposed link between false-alarms on the SSDT and MUS and suggests that under conditions of ambiguity, those prone to MUS report more false-alarms.

Adding to these studies Katzer, Oberfeld, Hiller and Witthöft (2011) and Brown et al. (2012) examined the relationship between physical symptom reporting and its link to experience somatic misperceptions – as evidenced by the frequency of false-alarms on

SSDT. In both studies, self-reported physical symptoms (measured by the patient health questionnaire; PHQ; Kroenke, Spitzer & Williams, 2002) were positively associated with false-alarm rates on the SSDT. Further regression analyses revealed false-alarms to be a strong predictor of self-reported physical symptoms (Brown et al., 2012) thus providing evidence for a robust link between physical symptom reporting and experimentally induced misperceptions of the body. Increased false-alarm rates in these studies may therefore, reflect reduced thresholds for activating somatic representations in memory (*i.e.*, according Brown, 2004) or an inability to discriminate signal from noise perhaps due to improved body focused attention (*i.e.*, according to Rief and Barsky, 2005) and are therefore in line with clinical models of MUS. By this view, MUS may reflect dysfunctional modulation of top-down cognitive processes.

2.5 Clinical models of MUS

It has been estimated that in primary health care settings, physical symptoms account for nearly half the out-patient visits (Schappert & Burt, 2001) and a third of these symptoms remain medically unexplained (Kroenke & Mangelsdorff 1989; Brown 2004; Jackson & Kroenke, 2008). MUS may take various forms, with pain, fatigue, gastrointestinal disorders and sexual dysfunction more commonly found in primary health care settings. In neurological settings, symptoms are classified as being either positive or negative. Positive symptoms are characterised by the presence of disrupting symptoms such as tremors and pseudo-hallucinations, while negative symptoms are characterised by a loss or drop in normal functioning and include sensory loss, paralysis, amnesia etc. (Brown 2004).

Psychological factors appear to play a central role in the development and maintenance of these unexplained symptoms. For example, negative affect has been shown to be associated with self-reported health and stress scales (Watson and Pennebaker, 1989) and also contributed to the progression of MUS (De Gucht, Fischler, Heiser, 2004). Neuroticism has been found to relate to distress in daily life (Bolger & Schilling 1991) and decreased life satisfaction leading to physical illnesses such as Asthma (Huovinen, Kaprio & Koskenvuo, 2001). A meta-analytic review also found a relationship between tendencies to report MUS and depression and anxiety (Henningsen, Zimmermann & Sattel, 2003). As a result, most models proposed to explain MUS have taken into account the role played by these factors.

2.5.1 The dissociation model

Janet's (1889) dissociation theory provides the earliest known systematic account of MUS and focuses on the role of traumatic experiences in the development of such unexplained symptoms. According to the model, traumatic experiences are followed by a spontaneous narrowing of attention that leads to a reduction in the amount of sensory information one can attend to. As a result, individuals become more likely to focus on some sensory channels whilst neglecting others. Information in these (neglected) sensory channels are still processed, however in a 'dissociated' manner and do not enter conscious awareness, therefore, giving rising to negative symptoms such as unexplained sensory loss. Janet also suggests that the narrowing of attention could limit awareness of information relating to the traumatic event and thus prevents these new memories from being integrated with the individual's pre-existing personal knowledge. As a result, the individual has minimal control over the activation of these memories, resulting in them

being easily triggered by internal or external events in their environment and are expressed as a ‘current reality’ instead of memories, resulting in positive symptoms such as pain.

In line with this model, a number of studies have found links between traumatic life events and dissociative experiences (Gershuny & Thayer 1999). Higher reports of dissociative experiences were also reported in patients with unexplained symptoms (Brown, Schraq & Trimble 2005; Gupta & Gupta 2006 – elevated dissociation scores in patients with MUS) and more unexplained symptoms seen in patients with dissociative disorders (Nijenhuis, Spinhoven, Vanderlinden, Van Dyck, & Van der Hart, 1998).

Although, this model proposes a potential link between trauma and MUS, evidence in support of it has been rather mixed. For example, not all patients with MUS report trauma, hence the dissociation model may not account for all clinical cases of MUS (Roelofs & Spinhoven, 2007). A study by Gold, Ketchman, Zucker and Cott (2008) found only a poor relationship between self-reported unexplained symptoms and dissociation, while other studies have found links between dissociation and MUS to disappear after controlling for trauma (Pribor, Yutzy, Dean & Wetzel, 1993) and links between trauma and dissociation disappear when controlled for general psychopathology. As a result, collective evidence from these reports suggests that in addition to dissociation, various pathogenic mechanisms may also contribute to the development and maintenance of MUS (Roelofs & Spinhoven, 2007).

2.5.2 The conversion model

Built upon the dissociation theory is the conversion model. According to this model, individuals cope with negative experiences by unconsciously repressing the activation or recall of memories associated with any traumatic event. In this way, the individual is protected from any negative affect associated with the traumatic experience. As a result the psychological trauma associated with negative affect will still be present, and is subsequently converted into somatic symptoms that may symbolise the traumatic event in some way. In this view MUS appear to play a defensive role (Breuer & Freud, 1991).

The model does not however account for all clinical and research data available, as empirical support for the model is limited (c.f. Roelofs & Spinhoven, 2007). If according to the model, psychological distress is expressed as somatic symptoms, it is expected that patients with MUS would have reduced levels of psychological distress - however, most studies of MUS have found robust positive correlations between unexplained somatic symptoms and psychological distress (Kroenke, 2003) suggesting that perhaps this model may lead to the development of MUS in only a sub-group of patients (Roelofs & Spinhoven, 2007).

2.5.3 Somatisation and cognitive behavioural models

Whereas the dissociation and conversion models focused more strongly on the processes or mechanisms responsible for the creation of MUS the somatisation model emphasises on factors underlying the formation of unexplained symptoms and the link between them. The model considers biological, psychological and social factors to be important in the formation and maintenance of unexplained somatic illnesses. Kirmayer

and Taillefer (1997) highlighted the role of everyday psychological processes and emotional arousal in the development of MUS. According to the model, the above mentioned processes capture varying degrees of attention, which sometimes results in them being misinterpreted as symptoms or signs of diseases. Such symptoms generate illness worry, catastrophizing and demoralisation (Brown, 2004) thus making the individual adopt a sick role which ultimately leads to help seeking – *i.e.,* assessment and treatment for the condition. In this way the individual is exposed to social factors such as media or even the reaction of family members/friends which further reinforces illness experiences. This process could be moderated by previous illness experiences, illness worry as well as the individual's personality, attention and autonomic reactivity. Therefore, in addition to providing an account of how different factors are linked together creating MUS, the model also provides an account of how normal illness behaviour could lead to extremely debilitating circumstances. Although compelling, the model only provides a very general overview of how various factors interact to create and maintain MUS and has therefore been criticised – the precise mechanisms underlying the interaction between biological, psychological and social factors are not clear. This makes it difficult to make distinctions between various types of MUS – *i.e.,* unexplained symptoms relating to depression/anxiety, MUS that arise as a result of a misinterpretation of normal or benign somatic sensations and symptoms that are not physical or psychiatric by nature such as unexplained blindness or paralysis (Kirmayer & Robbins, 1991a; 1991b).

The cognitive behavioural model on the other hand considers cognitive, behavioural and physiological factors as important contributors to the maintenance of

MUS. The model assumes that symptom development and maintenance relies on the interaction between various factors belonging to three different domains. A review by Deary et al. (2007) suggested that the cognitive behavioural model of MUS results from predisposing, precipitating and perpetuating factors.

Predisposing factors include the influence of genetics, early experiences and neuroticism. Both unexplained fatigue and unexplained somatic symptoms have been found to have genetic influences (Kendler et al., 1995; Farmer, Scourfield, Martin, Cardno & McGuffin, 1999; Hickie, Kirk & Martin, 1999). In terms of early experiences Fiddler, Jackson, Kapur, Wells and Creed (2004) compared links between childhood adversity and frequency of medical visits in patients with medically explained and unexplained symptoms. Significant links between the two were only seen for the MUS group with sexual abuse and overt neglect being most strongly associated with frequency of consultations. Moreover, children whose parents have medical conditions have been found to develop similar symptoms through a process of vicarious learning, thus leaving the symptom origins unexplained (Hotopf, 2003). Given that neuroticism is linked to a range of physical symptoms including asthma (Huovinen et al., 2001) it is unsurprising that a link between MUS and neuroticism would exist. In a recent study, De Gucht et al. (2004a) found neuroticism to be the most significant determinant of changes (*i.e.*, increase and decrease) in the number of unexplained symptom reports over time. More importantly, neuroticism was found to contribute to both symptom evolution and symptom persistence.

Precipitating factors are thought to trigger the start of symptom perpetuation. According to Deary et al. (2007) particularly traumatic life events have been the most

widely studied precipitating factor in relation to the cognitive behavioural model. Links have often been made between abuse and other traumatic life experiences and MUS. Wahlström, Michélsen, Schulman, Backheden, and Keskinen-Rosenqvist (2013) found disaster experiences to mediate MUS at a later time point in life (14 months post-disaster). Additionally, MUS have been found to be more commonly reported in patients of sexual trauma. It should however be noted that neuroticism is strongly associated with stressful life events (Kendler, Gardner & Prescott, 2003) and is therefore a potential confound of research in this area. Whereas the dissociation and conversion models consider trauma to be a predisposing factor involved in the formation of MUS, cognitive behavioural models explain how adverse life experiences could lead to the perpetuation of symptom experiences – *i.e.*, how cognitive and behavioural processes interact with somatic factors to produce physical symptoms. By this view, precipitating life events could increase physiological and behavioural responses to stressful events in the future due to heightened sensory awareness through a process of prolonged/chronic activation.

Heightened awareness to somatic sensations and increased somatic vigilance are thought to be involved in symptom *perpetuation*. As a result normal or benign somatic sensations maybe misinterpreted as pain (or other illnesses) which may lead to further somatic vigilance (Rygh et al., 2005). In addition to somatic attention and hypervigilance, illness attributions and illness beliefs have also been found to be important factors in the perpetuation of MUS (Deale, Chalder & Wessely, 1998; Hotopf, 2004; Henningsen, Jakobsen, Schiltenwolf & Weiss, 2005). Making such illness attributions leads to increased experience of symptoms and illness behaviours creating a vicious cycle. A drawback of research in this area however is the inability to theoretically and empirically

isolate factors contributing to symptom perpetuation. For instance, body focused attention and illness attribution may be informed by illness beliefs which in turn affect behaviour. Therefore, as previously mentioned the model only focuses on the interaction between these factors and their influence in the development and maintenance of MUS. As in the somatisation model, cognitive behavioural models also place little emphasis on the mechanisms by which cognitive and behavioural factors interact to produce physiological symptoms. Despite there being evidence in support of these models, the findings show a great deal of variability. Furthermore, as mentioned earlier, individual differences in personality often play significant roles in mediating the influence of these factors. Later models of MUS have more specifically focused on the perpetual processes responsible for the development and maintenance of MUS with emphasis placed on the underlying mechanisms (with increased perceptual sensitivity and reduced perceptual threshold).

2.5.4 Perceptual processing models

People vary greatly in their sensitivity to somatic sensations (Steptoe & Vögele, 1992; Barsky, Orav, Delamater, Clancy & Hartley, 1998). According to the amplification model, those with an increased tendency to experience normal bodily sensations as being particularly disabling and distressing are referred to as somatosensory amplifiers and those with reduced sensitivity to somatic sensations are known as reducers (Barsky 1992). Amplification of somatic sensations is thought to be shaped by genetic components and/or early childhood experiences (Barsky, Goodson, Lane & Cleary, 1988) as well as other factors such as mood and circumstances – thus giving it both trait and state properties respectively (Barsky et al, 1998). This model identifies three elements responsible for amplification, (i) somatic hypervigilance that increases attention to

unpleasant sensations (ii) a greater tendency to selectively concentrate on benign sensations, and (iii) an increased propensity to assign benign somatic sensations to serious illnesses as opposed to treating them as normal changes in bodily processes (Barsky et al., 1988). By this view, peoples' thoughts and concerns could reinforce benign symptoms causing them to be experienced as being more disabling and alarming (Ravenzwaaij et al., 2010). Although, this model provides a useful explanation for the development and maintenance of unexplained symptoms in the absence of any organic pathology, it can also be used explain conditions such as hypochondriasis as well as other mental disorders with physical symptoms such as depression and panic disorders (Barsky, 1992) hence evidence of its role in MUS itself is limited (Barsky et al., 1988; Young 2008).

In a more recent model proposed by Rief and Barsky (2005) perceptual processes were again regarded as important in symptom creation and maintenance. In contrast to somatosensory amplification (Barsky, 1992) this model suggests MUS to be associated with a filtering deficit in which a disruption in the normal filtering of somatic sensations (or signals) is regarded as the central pathogenic process involved in the creation and maintenance of unexplained somatic symptoms. The model proposes a framework through which symptoms are created and maintained via two stages. The first stage involves the amplification of somatic sensations by factors including over arousal, distress and hypothalamus pituitary adrenal axis (structures mediating stress responses) activation. While in healthy individuals a hypothetical filter system filters out these irrelevant sensations (or sensory noise) preventing it from entering consciousness, this filter is dysfunctional in those with MUS due to depression, health anxiety and

abnormalities in attention. Therefore, irrelevant somatic sensations enter conscious awareness and are misperceived as signs of illnesses (Rief & Barsky, 2005; Deary et al., 2007). Despite there being only limited evidence in support of the model, in comparison to previous models of MUS; the signal filtering model is simpler and straightforward. The model takes into account roles played by cognitive processes and provides well-grounded explanations for the mechanisms underlying the development and maintenance of MUS.

2.5.5 An integrative conceptual model

Brown (2004) also put forward a model for the development and maintenance of MUS. This model integrates previous concepts of dissociation, conversion and somatisation; however the central premise of this model is cognitive. According to the model, MUS result from distorted memories generated by symptom related information or rogue representations. Rogue representations are false symptom perceptions and refer to information relating to the nature of symptoms. These can be acquired from various sources including exposure to physical states of self and others (during times of illness or traumatic life experiences), sociocultural transmission and verbal suggestion (Brown, 2004; Rief & Broadbent, 2007). These rogue representations are activated by two hypothetical attentional systems – the primary and secondary attentional system. The primary attentional system is an automatic information processing system that selects rogue representations which are then moderated and facilitated by the secondary attention system through excessive body focused attention, negative affect and disease confirming information. In this sense, the secondary attentional system facilitates the re-activation of these symptoms resulting in the maintenance and development of symptom chronicity.

Therefore, paying a great deal of attention to the body and scanning for signs of a disease leads to the development of unexplained physical symptoms. This integrative conceptual model of MUS link perceptual and cognitive processes and in line with the signal filtering model acknowledges the roles played by various components in the evolution and maintenance of unexplained somatic symptoms.

Each model described above has improved the understanding of MUS. The models offer unique perspectives of different risk factors that contribute to the development of MUS and the mechanisms by which they interact. While there is a considerable amount of overlap between the proposed models of MUS, clear problems have been identified and were discussed in traditional models of MUS including dissociation, conversion, somatisation and the cognitive behavioural model. More recent cognitive models by Brown (2004) and Rief and Barsky (2005) have taken into account the roles played by memory and attention in modulating sensory signals relating to the body. By this view individuals with MUS or tendencies towards MUS are characterised by disproportionate amounts of top-down cognitive reliance. Examining individual differences in the tendency to misperceive or misinterpret somatic events would therefore provide much needed empirical support for these recent models and aid to elucidate the proposed links between top-down reliance and perceived somatic sensations (both aversive and benign).

2.6 Individual differences in somatic misperceptions

Studies aiming to provide empirical evidence for models of MUS have examined how individual differences in MUS are associated with risk factors such as tendencies

towards displaying somatic hypervigilance, excessive body focused attention and trauma among others. Brown, Poliakoff and Kirkman (2007) examined whether a bias in detecting tactile or visual target stimuli was influenced by prior exposure to threatening or non-threatening photographs of body parts in individuals with increased/decreased propensities towards MUS (as measured by the SDQ-20). Increased tendencies towards MUS were associated with a bias towards detecting more tactile targets following exposure to threatening body-related photographs. This immediate shift to the tactile modality when confronted with somatic threat may perhaps reflect a protective action and rule out general tendencies to focus on the tactile modality. As a result probabilities of misinterpreting somatic threat may increase, eventually leading to the creation and maintenance of MUS (Rief & Barsky, 2005). The authors also examined whether self-reported somatic amplifications scores (measured using the somatosensory amplification scale; Barsky, Wyshak & Klerman, 1990) was related to this bias in tactile detection and found a negative association between the two following exposure to both threatening and non-threatening photographs. While this finding contradicts the amplification model of MUS, it suggests that when exposed to body related information, somatic amplifiers may direct focus away from the body perhaps as a means of reducing any influence from disturbing somatic sensations. In a later study, the time-course of attention to touch was compared in participants with increased and decreased tendencies towards MUS following exposure to either a neutral or traumatic film (Brown, Danquah, Miles, Holmes & Poliakoff, 2010a). A cue-target task indicated that, those with increased tendencies towards MUS, displayed greater delays in disengaging attention from the tactile cue at larger stimulus-onset-asynchronies (SOA) after being exposed to the neutral film

indicating dysfunctional body focused attention in such individuals. In contrast, following the traumatic film the influence of the cue was reduced even at lower SOA. Therefore, rather than becoming more body focused under conditions of stress (or trauma), propensities towards MUS might be associated with immediate somatic avoidance. The authors, however, suggested that avoiding bodily information may perhaps lead to increased reliance on top-down information (*e.g.*, beliefs, expectations and knowledge) when generating somatic experiences relating to the body. This in turn could lead to overactive somatic representations in memory which could ultimately lead to MUS according Brown's (2004) model. The study's findings are twofold; (1) MUS are associated with reduced disengagement form the body under general conditions (perhaps due to somatic hypervigilance) however; (2) MUS are also associated with somatic avoidance under stressful or traumatic situations.

Further extending these studies, Miles, Poliakoff and Brown (2011) examined whether participants' responsiveness to somatic illusions – particularly the RHI (Botvinick & Cohen, 1998) reflected individual differences in MUS. Given that synchronous visuo-tactile stroking (bottom-up processes) and postural congruence (top-down processes) are important in eliciting the illusion (Tsakiris & Haggard, 2005), susceptibility to the illusion would shed light on the precise mechanisms underlying formation of MUS. Individuals with reduced tendencies towards MUS showed greater susceptibility to the RHI compared to individuals with greater propensities towards MUS. This finding is line with cognitive models of MUS that have suggested disproportionate top-down reliance in such individuals. As a result, they would hold perceptions about their body that are more in keeping with reality whereas healthy individuals would have

been strongly influenced by the sensory information in the RHI. Moreover, McKenzie and Newport (2015) found those with increased tendencies towards MUS to report more interoceptive somatic sensations following visual illusions that changed the appearance of the skin. Such individuals would have therefore, displayed greater visual attention to the hand during the illusions which may have created somatosensation. In this way MUS are associated with a top-down modulation of sensory signals.

In addition to reflecting individual differences in MUS, illusions have also been useful indicators of other bodily distortions. Burrack and Brugger (2005) found that increased tendencies to experience body related abnormalities in everyday life (measured using the perceptual aberration scale; Chapman, Chapman & Raulin, 1978) was positively linked to an experimentally induced somatic distortion- the illusory arm extension following tendon vibration (Lackner, 1988; de Vignemont et al., 2005). Individuals suffering from disorders characterised by disturbances in the body image such as schizophrenia and body dysmorphic disorder are found to be more susceptible to the RHI – thus highlighting the malleability of their body representation (Thakkar, Nichols, McIntosh & Park, 2011; Kaplan, Enticott, Hohwy, Castle, Rossell, 2014). Susceptibility to the RHI is therefore a valuable and objective tool in identifying individuals prone to psychopathologies involving distorted body representations. Given that illusion therapy and body size magnification/minification have been useful in correcting somatic distortion and relieving pain in patients experiencing chronic pain (Moseley et al., 2008; Preston & Newport, 2011) perhaps identifying characteristics of individuals who are most susceptible to somatic illusions maybe useful indicators of individuals most likely to benefit from such illusion treatment.

2.7 Aims and objectives of the current Thesis

The research described thus far has provided descriptions of how sensory inputs from different modalities are integrated to form and shape somatic events and experiences. As described in Chapters 1 and 2, somatic experiences could be distorted under various circumstances including psychopathologies and experimentally induced alterations to sensory input that create illusory experiences. In line with this, traditional studies have demonstrated asymmetric tendencies towards acknowledging and incorporating larger but not smaller body sizes into the body representation (Pavani & Zampini, 2007; Haggard & Jundi, 2009), however, these suffered from many methodological limitations. Recent studies have provided evidence for bidirectional flexibility of the body representation using indirect scaling techniques and/or in virtual environments (Bruno & Bertamini, 2010; Linkenauger, Leyrer, Bülthoff & Mohler, 2013; Banakou, Groten, & Slater, 2013) which in turn could be also criticised for reduced realism. For example, the virtual bodies may not possess the same level of realism and identity as one's actual body and may also provide reduced depth cues (Linkenauger et al., 2013). Therefore, at present unequivocal conclusions about the mechanisms underlying altered somatic experiences cannot be drawn. This thesis therefore aimed to directly (*i.e.*, without scaling techniques) investigate the mechanisms underlying susceptibility to illusions of altered body size using realistic somatic illusions, that provided online alterations to the body representation. Given that altered perceptions of body size have also been found to alter subsequent somatic sensations (Kennett et al., 2001; de Vignemont et al., 2005), the thesis also examined the mechanisms by which such illusions may alter external tactile perception. Finally, as susceptibility to such

illusory and perceptual phenomena display large individual differences (Chapter 2), the thesis also addressed this as a secondary aim.

Chapter 3 describes a pilot investigation that aimed to explore subjective illusion susceptibility and ownership over a range of size altered body-part representations, using somatic illusions (*i.e.*, stretched and shrunken finger/hands) induced using the MIRAGE mediated reality system. Chapter 4 investigated how illusory stretching and shrinking of a body part altered perception of that body part; *i.e.*, increased/decreased ownership and/or changed perceived size of that body part, reflecting temporary alterations of how the body part is mentally represented. Chapter 5 examined how such somatic illusions altered external tactile sensations; increased/reduced sensitivity or response bias. Chapter 6 further examined the link between illusions and tactile perception using a visual illusion that was designed to create somatic sensations on the skin in the absence of any real somatosensory input, with the aim of understanding the influence of top-down somatic manipulations on bottom-up sensory processes. Individual differences in participant's response patterns were examined in all experimental chapters (except Chapter 3) with the aim of increasing our understanding of how each study would be clinically relevant, and to broaden conceptual knowledge of the processes that might underlie susceptibility to various somatic distortions including chronic pain and MUS. Finally, Chapter 7 discusses the overall findings of this empirical research in relation to proposed theoretical models and concludes with practical implications of the current work, and suggestions for future research.

CHAPTER 3

EXAMINING THE DEGREE OF SUBJECTIVE SUSCEPTIBILITY TO MULTISENSORY ILLUSIONS OF BODY SHAPE AND SIZE

Abstract

Participants' susceptibility to somatic illusions provides a means of examining the mechanisms underlying clinical conditions including chronic pain and phantom sensations. This chapter reports a study aimed at examining the degree of susceptibility to a series of visuo-proprioceptive size altering illusions generated using the MIRAGE mediated reality system. Participants made illusion strength and ownership ratings to the following illusions: stretched finger, shrunken finger, stretched hand and shrunken hand as well as to a veridical condition with no illusion. Results indicated that participants felt their hand and finger to be altered in the direction of the manipulation following the illusions but not the veridical condition. Susceptibility to these illusions validates manipulations induced using the MIRAGE system and may be useful in the development of potential treatment options to correct distorted body representations in clinical populations.

3.1 Introduction

Many clinical conditions are characterised by distorted somatic experiences. For example, numerous patient reports have described the presence of painful phantom limbs in up to 80% of amputees (phantom limb syndrome; Ramachandran & Hierstien, 1998). The presence of one or more supernumerary phantom limbs is also reported on the contralesional side of the body following damage to the right hemisphere (Halligan &

Marshall, 1993; Halligan, Marshall & Wade, 1993). Such misperceived phantom sensations have been experimentally investigated through simple manipulations to sensory inputs that give rise to somatic illusions in healthy individuals. For example, the ubiquitous rubber hand illusion (RHI; Botvinick & Cohen, 1998) in which synchronous (but not asynchronous) stroking of a fake rubber hand and the unseen real hand, creates a feeling of ownership over the rubber hand and has provided evidence for the role of top-down and bottom-up factors contributing to the feeling of body ownership (Taskiris & Haggard, 2005). This illusion has also provided evidence for the existence of multiple body representations (Kammers, de Vignemont, Verhagen & Dijkerman, 2009) including body image and body schema (Paillard, 1999) as well as the cortical regions associated with maintaining the sense of body ownership (Ehrsson, Spence & Passingham, 2004). Susceptibility to the RHI is also an indicator of clinical conditions characterised by distorted body representations such as schizophrenia (Germine, Benson, Cohen, & Hooker, 2013), eating disorder symptoms (Mussap & Salton, 2006) and tendencies towards medically unexplained symptoms (Miles, Poliakoff & Brown, 2011). The RHI is therefore, one of many examples that suggest somatic illusions induced via sensory manipulations can provide insight into the development of distorted somatic experiences. Understanding the conditions under which somatic perceptions could be experimentally manipulated would, therefore, be of therapeutic value in the development of treatment options for conditions that include somatic distortions.

In addition to the distorted somatic experiences characterised by the presence or absence of body parts, some others are characterised by a perceived alteration of body size, as seen in many chronic pain states (Peltz, Seifert, Lanz, Müller & Christian

Maihöfner). As such, somatic illusions of perceived body shape and size may be useful in understanding the nature of the body size distortions underlying pain and have indeed previously been found to temporarily alleviate both chronic (Preston & Newport, 2011) and acute pain (Mancini, Longo, Kammers & Haggard, 2011). Previous research indicates that a majority of the population is susceptible to such illusions with up to 93% reporting that their finger was stretched following a visuo-proprioceptive size altering illusion (Newport et al., 2015). However, empirical evidence of susceptibility to shrunken body representations is both limited and mixed (Pavani & Zampini, 2007; Haggard & Jundi, 2009) and these previous investigations have not systematically assessed subjective ratings of illusion susceptibility and ownership over the manipulated body representations (Newport et al., 2015). Therefore, prior to examining how somatic illusions provide insight into the mechanisms underlying the formation and treatment distorted body representations, the degree of illusion susceptibility and ownership should be examined.

Chapter 3 reports a pilot study that aimed to examine the extent to which participants experienced alterations to body shape and size, as well as how strongly ownership is claimed over such altered somatic representations. The MIRAGE mediated reality system was used to administer a range of visuo-proprioceptive illusions in which perceived size of the index finger and hand was either stretched or shrunken. Participants made ratings of illusion strength by indicating how strongly they felt each manipulation, as well as ratings of ownership by indicating how strongly each manipulated body-part representation was felt to belong to them, using a 9 point rating scale.

3.2 Methods

3.2.1 Participants

Fourteen right-handed (Edinburgh Handedness Inventory 20; Oldfield, 1971; Appendix 1; see also Appendix 3.4 for range) participants (2 male) aged 17 to 21 years (mean age=19.14; SD=0.86) were recruited. Written informed consent was obtained prior to participation and none of the participants reported any sensory deficits. All procedures were approved by the University of Nottingham Malaysia Campus Research Ethics Committee. Participants were compensated with course credit for their participation.

3.2.2 Apparatus and Material

a) MIRAGE mediating reality system

The MIRAGE system consists of an arrangement of mirrors and cameras that provides participants with real-time video images of their limbs. The position and angles of the mirror and camera is such that participants view life-sized video images of their own limb(s) in its veridical location. The mirror is located in a frame 320mm above the table top. A 22 inch NEC Multisync E222w LED monitor is placed 320 mm face down above the mirror. Images captured via the camera are reflected by the mirror and the monitor. The images may either be displayed un-manipulated or can be manipulated via custom software with a delay less than 17ms (found to be behaviourally negligible; Newport, Preston, Pearce & Holton, 2009; Newport, Pearce & Preston, 2010). Using the device the experimenter can create purely visual illusions or provide participants with concurrent tactile feedback that creates convincing visual and proprioceptive illusions, including stretched and shrunken fingers, disappeared hands and even multiple

representations of the same limb. Typically participants are seated in front of the device and are able to view their hands through the mirror. In the current study, images captured by the camera were manipulated to create four convincing multisensory illusions; ‘stretched finger’ ‘shrunken finger’, ‘stretched hand’ and ‘shrunken hand’ (see Figure 3.1).

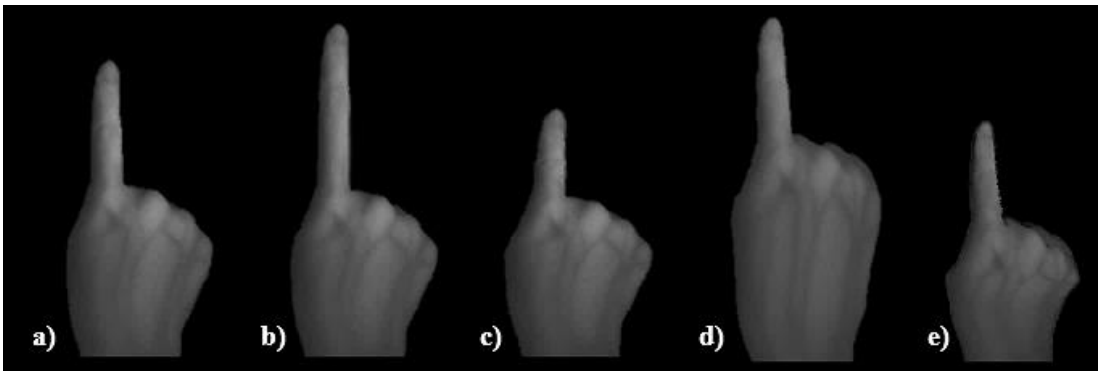


Figure 3.1a-e: Multisensory illusions: (a) Veridical condition (no manipulation), (b) Stretched finger (c) Shrunken finger (d) Stretched hand (e) Shrunken hand

During the stretched illusions, the experimenter grasped and pulled participants’ index finger/hand with slight pressure. Simultaneously, the video image of the index finger/ hand was seen to increase in length until the size of the finger/hand was approximately double its original length. During the ‘stretched finger’ illusion, the region of the finger from the middle knuckle expanded outwards resulting in an increase in the visual area of the finger. During the ‘stretched hand’ illusion, the mid-dorsal region of the palm expanded outwards and increased in length. For the shrunken illusions, participants’ finger/hand was gently pushed in with light pressure. The video image of the index finger/ hand was seen decrease in size (by approximately half its original length). As in the stretched finger illusion, when the finger was shrunken, the region corresponding to the middle knuckle was seen to shrink resulting in a decrease in visible area of the finger.

Similarly, during the ‘shrunken hand’ illusion the mid-dorsal region of the palm shrank and moved inwards (see Preston & Newport, 2011).

b) Questionnaire measures

Acclimatisation questionnaire (see Appendix 2.1): The acclimatisation questionnaire (Newport, Pearce & Preston, 2010) consisted of six items (*e.g.,* ‘It seemed like the image of the hand was my own’, ‘It seemed like the image of the hand belonged to me’) that measured sense of ownership over the video image of the hand when seen through the mirror of the MIRAGE mediated system in its actual location, prior to the application of any illusions.

Illusion strength and ownership questionnaires (see Appendix 2.2 – 2.6): These questionnaires aimed to assess the extent to which each illusion was incorporated into participants’ body representation (adapted from Preston & Newport, 2012). They measured how strongly participants felt each multisensory illusion (*e.g.,* ‘I felt like my finger/hand was really being stretched/shrunken’) and participants’ sense of ownership towards the distorted appearance of their finger/hand (*e.g.,* ‘I feel like I am watching myself’/ ‘I feel like I am watching someone else’).

In both the acclimatisation and illusion strength and ownership questionnaires, participants made verbal judgements on a 9 point numeric rating scale in which 9 indicated strong illusion strength/ownership and 1 indicated low illusion strength/ownership.

3.2.2 Procedure

Upon being seated in front of the MIRAGE system, participants were given a brief period of acclimatisation (~20 seconds) during which time they were encouraged to move both hands within the device. During this period of acclimatisation, participants were free to move their hands within the device in any way they wanted. This was followed by the 6 item acclimatisation questionnaire. Participants were then instructed to take their left hand out after which they responded to questionnaires regarding the perception of their veridical hand in the absence of any illusions. Participants responded to statements adapted from those included in the illusion conditions (*e.g.,* 'I feel like my finger/hand is longer/shorter than normal', 'I feel like I am watching myself/someone else'). This condition was followed by one of the four illusion conditions (stretched finger, shrunken finger, stretched hand, or shrunken hand) which were conducted in a counter balanced order. As mentioned above, during each illusion, the experimenter either gently pulled or pushed the participants' finger/hand while they watched their finger/hand grow longer or shorter than its veridical length. Participants were instructed to keep their hands still following the application of each multisensory illusion. Once the illusion had been applied, the experimenter reached for and touched the participants' finger/hand and asked them whether or not they felt the touch, with the aim of providing congruent visuo-tactile feedback to indicate that participants were still watching their hand, and ensure that they still felt ownership over this manipulated visual representation. Illusion strength and ownership questionnaires corresponding to each multisensory illusion condition were then conducted, and took approximately 45 seconds after which participants' finger was brought back to its original length. Each condition (veridical and

illusions) was repeated three times and participants were given a break (~ two minutes) at the end of each condition during which time they were asked to take their hand out of the MIRAGE system and encouraged to move it to reset finger or hand length.

3.3 Results

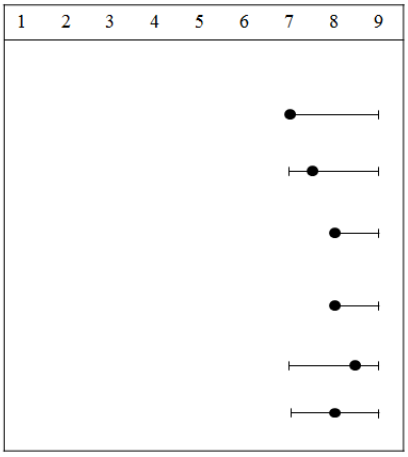
Questionnaire ratings were significantly negatively skewed and remained not normally distributed (Shapiro Wilk statistic showed that $p<.05$) despite attempts to transform the data; consequently non-parametric analyses were conducted.

Acclimatisation questionnaire: Responses indicated strong ownership towards the live video images of the hands. Participants strongly agreed with statements such *as 'It seemed like the image of the hand was my own'* (Median= 8.5) and *'It seemed like the image of the hand belonged to me'* (Median=8; see Figure 3.2a).

Illusion strength and ownership questionnaires: A mean rating for each statement in each condition was obtained by averaging responses in each trial. Ratings indicated that participants felt their finger and hand to be stretched or shrunken but still claimed ownership over these manipulated representations of the finger (see Figure 3.2b).

a) Acclimatisation questionnaire

	Acclimatisation
The video hand resembled my own hand in terms of shape, skin tone, freckles or some other visual feature.	
I felt as if the video hand were my hand.	
It seemed as if I were feeling touch on the table in the same location where I saw my hand being touched.	
It seemed as though the touch I felt was caused by the table touching my hand.	
It seemed like the image of the hand belonged to me.	
It seemed like the image of the hand was my own hand	



b) Illusion strength and ownership

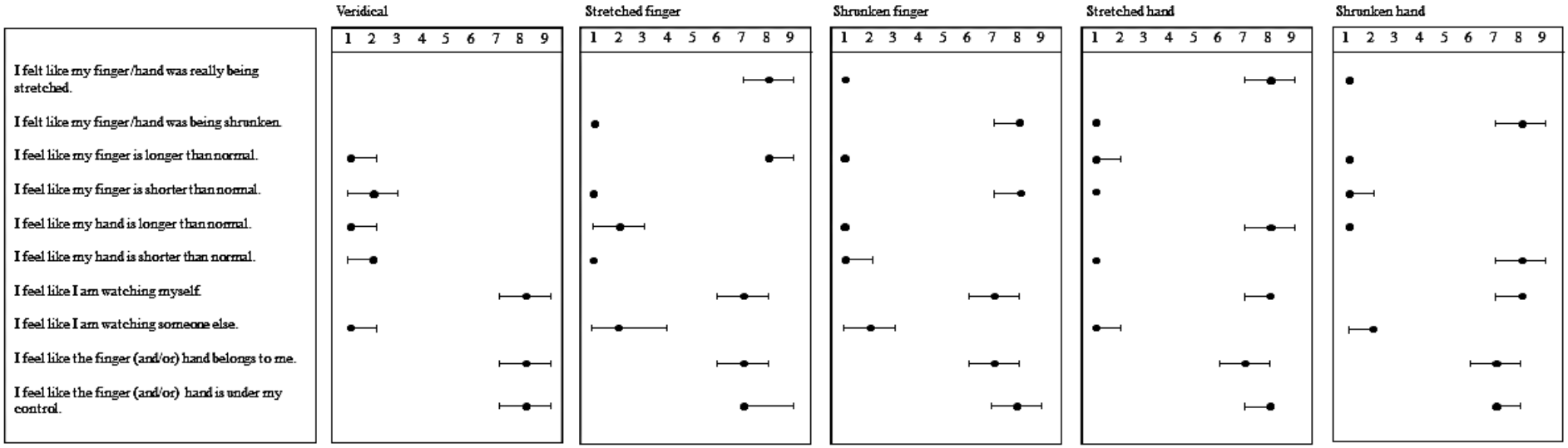
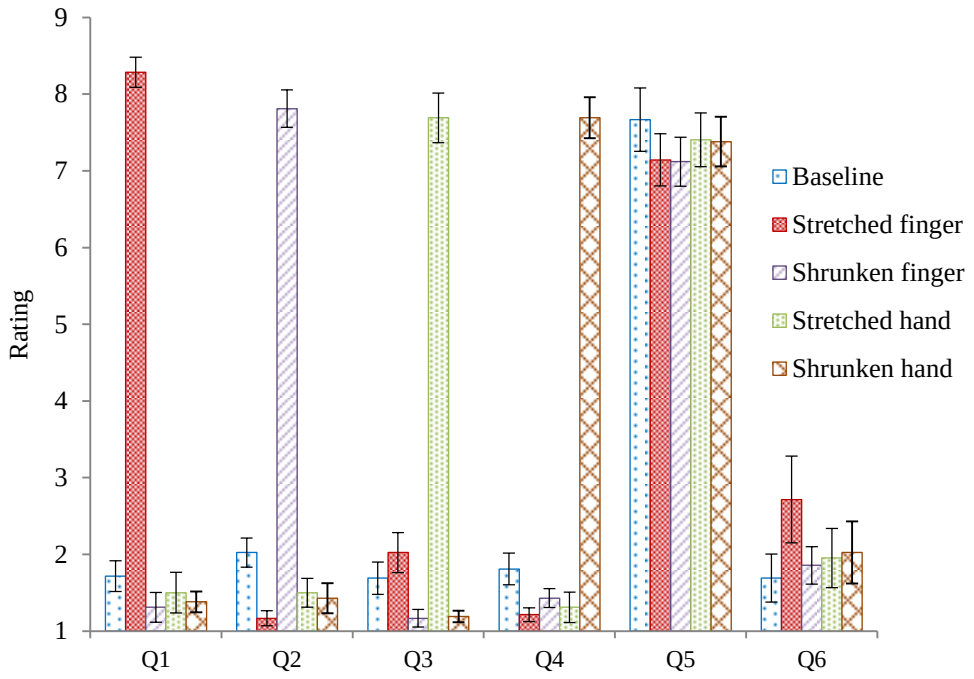


Figure 3.2a-b: Medians and inter-quartile ranges for illusion strength and ownership ratings: (a) Acclimatisation (b) Illusion strength and ownership

Statements *'I feel like my finger is longer than normal'*, *'I feel like my finger is shorter than normal'*, *'I feel like my hand is longer than normal'*, *'I feel like my hand is shorter than normal'* reflected illusion strength across the conditions while statements *'I feel like I am watching myself'*, and *'I feel like I am watching someone else'* reflected ownership across all conditions. These statements were also common across all 5 conditions (veridical and illusion) and were therefore compared. A Freidman's ANOVA revealed significant differences in illusion strength scores for the statement *'I feel like my finger is longer than normal'* across the conditions (χ^2 (4, N=14) = 42.20, p<.001). Bonferroni corrected (α=.005)Wilcoxon signed-ranks tests indicated higher illusion strength ratings during the stretched finger illusion (Median= 8.5) compared to the veridical condition (Median= 1; Z= -3.32, p=.001, r=.89), the shrunken finger condition (Median= 1; Z= -3.37, p=.001, r=.90), the stretched hand condition (Median= 1; Z= -3.37, p=.001, r=.90) and the shrunken hand condition (Median= 1; Z= -3.34, p=.001, r=.89). All other comparisons were not statistically significant (all p>.005). Similarly, a significant main effect was seen for the statement *'I feel like my finger is shorter than normal'* (χ^2 (4, N=14) = 45.16, p<.001). Wilcoxon signed-ranks tests indicated illusion strength to be significantly greater for the shrunken finger condition (Median= 8) compared to the veridical condition (Median= 2; Z= -3.33, p=.001, r=.89), the stretched finger condition (Median= 1; Z= -3.33, p=.001, r=.89, the stretched hand condition (Median= 1; Z= -3.33, p=.001, r=.89) and the shrunken hand condition (Median= 1; Z= -3.33, p=.001, r=.89). Participants also felt their finger to be significantly shorter during the veridical (Median =2) compared to the stretched finger condition (Median= 1; Z= -2.88, p=.004, r=.77) however, none of the other comparisons were significant.

A main effect of ratings were also seen for the statement *'I feel like my hand is longer than normal'* across the conditions (χ^2 (4, N=14) = 44.34, p<.001). Ratings to this statement were greater during the stretched hand condition (Median= 8) compared to the veridical condition (Median= 1; Z= -3.31, p=.001, r=.89), the shrunken hand condition (Median= 1; Z= -3.33, p=.001, r=.89), the stretched finger condition (Median= 2; Z= -3.31, p=.001, r=.89) and the shrunken finger condition (Median= 1; Z= -3.32, p=.001, r=.89). No other significant comparisons were significant (p>.005). Significant differences across the conditions were also seen for the statement *'I feel like my hand is shorter than normal'* (χ^2 (4, N=14) = 44.86, p<.001). Illusion strength ratings were significantly greater during the shrunken hand condition (Median = 7.5) compared to the veridical condition (Median= 2; Z= -3.35, p=.001, r=.90), the stretched hand condition (Median= 1; Z= -3.33, p=.001, r=.89), the stretched finger condition (Median= 1; Z= -3.32, p=.001, r=.89) as well as the shrunken finger condition (Median= 1; Z= -3.33, p=.001, r=.89). All other comparisons were not statistically significant (p>.005). No differences across the conditions were however seen for the statement *'I feel like I am watching myself'* (χ2 (4, N=14) = 3.46, p=.48) and *'I feel like I am watching someone else'* (χ^2 (4, N=14) = 7.98, p=.092) indicating that all participants retained a sense of ownership over their manipulated body representation following the illusions. Figure 3.3 below demonstrates these differences. In the interest of simplicity the figure represents means and standard errors of each statement.



Q1: I feel like my finger is longer than normal

Q2: I feel like my finger is shorter than normal

Q3: I feel like my hand is longer than normal

Q4: I feel like my hand is shorter than normal

Q5: I feel like I am watching myself

Q6: I feel like I am watching someone else

Figure 3.3: Mean illusion strength and ownership ratings across all five conditions. Error bars show standard error of the mean

3.4 Discussion

Somatic illusions have previously been found to alter participants' perception of their body representation (Botvinick & Cohen, 1998; Lackner, 1988) however; these empirical investigations have not always provided evidence of the extent of subjective susceptibility across participants. Indeed, in a recent study, Newport et al. (2015) demonstrated susceptibility to illusory finger elongation in over 90% of their sample but, using a two alternative forced-choice task. This chapter therefore reports a

pilot investigation conducted to assess the degree of illusion susceptibility and ownership over such manipulated body representations. The results indicated that participants strongly felt all illusory manipulations on their hand/finger and more importantly that this feeling was restricted to the body site at which the illusion was applied to. For example, participants did not report their hand to have increased in length along with their index finger, during the stretched-finger illusion. In comparison to previous studies reporting asymmetric tendencies towards acknowledging only enlarged body parts (Pavani & Zampini, 2007; Haggard & Jundi, 2009) the current findings reported no difference in ownership across stretched and shrunken body representations. These previous studies either used enlarged and shrunken static rubber hands or video representations of participants' hands, both of which did not provide gradual/dynamic alterations to the perceived body representation perhaps resulting in them appearing less realistic. Given one's reduced encounters with minified/shrunken representations, ownership towards such representations would have been far less.

Furthermore, in contrast to the illusion conditions, participants did not report their finger or hand to feel significantly longer or shorter during the veridical condition (in which no illusion was present) thus suggesting that the veridical condition serves as a valid control by which somatic perception following the illusions could be compared against. Collective findings of this study may also provide validation of the stretched and shrunken illusions generated using the MIRAGE mediated system by demonstrating altered somatic perceptions and thus lays the foundation for the rest of the empirical investigations conducted in this thesis. Finally, as illusion therapy has been useful in treating body representation related disorders (*e.g.*, chronic pain) susceptibility to MIRAGE induced somatic illusions

could lead to the development of promising treatment options in the future (Preston & Newport, 2011). The subsequent experimental chapters (4, 5 and 6) aimed to investigate the mechanisms by which these somatic illusions altered somatic perception and somatosensation as well as individual differences in such processes.

CHAPTER 4

ALTERED BODY REPRESENTATIONS FOLLOWING A BRIEF EXPOSURE TO MULTISENSORY DISTORTIONS OF THE HAND

Abstract

The dynamic flexibility of the body representation has been highlighted through numerous lines of research that range from clinical studies reporting disorders of body ownership, to experimentally induced somatic illusions that have provided evidence for ownership towards fake limbs, as well as manipulated representations of limbs. While most studies have reported that enlargement of body parts alters somatic perception, and that these can be more readily embodied, shrunken body parts have not been found to consistently alter somatic experiences, perhaps due to reduced ownership towards smaller body parts. Experiments 1 and 2, therefore, aimed to investigate the mechanisms responsible for altered somatic representations following both enlarged and shrunken body parts. Participants were given the impression that their hand or index finger was either longer or shorter than normal and asked to judge veridical finger/hand length using online and offline size estimation tasks. Participants also provided subjective ratings of illusion strength and ownership over the illusory manipulations. Ownership was claimed over the distorted representations of the hand and finger, while the online and offline tasks demonstrated differing response patterns. The online task showed that stretching and shrinking led to over – and underestimations of perceived body size respectively, thus providing evidence for altered mental representations of the body and suggesting that the flexibility of the body representation is more bidirectional than previously thought. The offline task revealed no overestimations following illusory stretching, suggesting that offline measures may not be sensitive to overestimations of perceived body representation

and thus highlighted differences between various methods of body size estimation. Experiment 3 examined individual differences in illusion susceptibility using the somatosensory amplification scale (SSAS). Results indicated a positive association between SSAS scores and illusion susceptibility for females but not males, suggesting that the SSAS may perhaps be a good indicator somatosensory sensitivity and illusion experience for females; possible reasons for this are explored in the Discussion.

4.1 Introduction

Successful physical interaction with the external environment requires a sense of ownership and embodiment towards the body, together with information regarding its position in external space. Numerous misinterpretations of somatic experiences have been reported following damage to cortical regions, including the premotor and parietal regions that are associated with maintaining an accurate body representation (Tsakiris, 2010). For instance, clinical studies of asomatognosia have shown that patients with acquired brain injury report disownership of their body or body parts (Arzy, Overney, Landis & Blanke, 2006a) which in some cases can also be attributed to another individual (somatoparaphrenia; Bisiach, Rusconi & Vallar, 1991; Vallar & Ronchi, 2009). Patients with body integrity identity disorder (BIID) express a strong desire to amputate a healthy limb because it feels alien (First, 2005; Brang, McGeoch & Ramachandran, 2008) while those with mesoplegia display dislike or hatred towards a limb resulting in urges injure it (Loetscher, Regard & Brugger, 2006).

Although such misperceptions of the body may appear to be features of pathological conditions, recent research has demonstrated that distorted somatic experiences are indeed characteristic of healthy body representations as well. For instance, large distortions in perceived body size are often reported in body image

tasks that require participants to compare the size of body parts (*e.g.*, the hand, finger) to the length of a line or in tasks requiring participants to localise in external space different landmarks (*e.g.*, fingertip) of their occluded hand (Longo & Haggard, 2010; 2012). Additional evidence for somatic misperceptions has also been demonstrated following experimental manipulation of the perceived shape and size of the body. For example, vibration of the biceps and triceps tendons have been found to give rise to an illusory extension and flexion of the forearm respectively, creating a feeling that the limb has been moved or displaced (Lackner, 1988) while a later study by Gandevia and Phegan (1999) found complete anaesthesia of the thumb induced via digital nerve block to significantly increase its perceived size. Collectively, these findings suggest that healthy body representations (despite intuitively seeming to be resistant to alterations) are flexible, and can be readily updated based on incoming sensory information that gives rise to altered somatic experiences.

Studies investigating the flexible and modifiable nature of body representations have reported large distortions in somatic perception following manipulations to perceived body shape and size. For example, Bruno and Bertamini (2010) found that manipulating perceived hand size altered the perceived size of held objects, such that objects were judged to be smaller or larger following exposure to enlarged and reduced models of the hand respectively. Using head-mounted displays, van der Hoort, Guterstam and Ehrsson (2011) demonstrated that owning a smaller body resulted in objects being perceived to be larger, whereas the opposite effect was seen when participants felt ownership over a larger body. Perception of the external environment (*e.g.*, visual perception of objects and distances) may therefore depend on one's perceived body representation which provides a sense of scale. Similar scaling effects are also reported in virtual environments following the embodiment of

different sized hands and bodies. In a series of experiments, Linkenauger, Leyrer, Bülthoff and Mohler (2013) demonstrated that the hand is used as a metric to scale the size of surrounding objects and that modifying the dimensions of the hand's representation altered the perceived size of objects. Using immersive virtual reality, Banakou, Groten and Slater (2013) found that embodiment of a virtual toddler body led to significantly greater overestimations of object size as compared to embodiment of a scaled down adult body. It should however be noted that these effects of altered somatic perception following manipulations to body shape and size have been found to be rather inconsistent. For instance, Haggard and Jundi (2009) found weight of a grasped object to be influenced by perceived hand size only following exposure to enlarged representations of the hand. In line with this finding, de Vignemont, Ehrsson and Haggard (2005) found reduced tactile two-point discrimination thresholds following illusory elongation of perceived finger size; whereas, no difference was seen following illusory shrinking. Moreover, in a modified version of the rubber hand illusion (RHI; Botvinick & Cohen, 1998) that involved video footage of the real hand, Pavani and Zampini (2007) only found the illusion to be elicited following exposure to veridical and enlarged representations of the hand. These findings therefore demonstrate asymmetric tendencies to acknowledge and integrate enlarged (or veridical) body parts into our body representation, thus creating a need to more closely inspect and further understand the mechanisms underlying the varied effects of such somatic illusions. The failure to produce alterations in somatic experiences with shrunken body parts in previous studies may suggest a lack of ownership over smaller body parts (Ramachandran & Ramachandran, 2007) perhaps due to bodily changes in the form of elongation or extension being more frequent and rapid (Pavani & Zampini, 2007; Haggard & Jundi, 2009). Moreover, a majority of these previous

studies have been limited to depictions of body parts that did not allow dynamic changes in perceived body size and were, therefore, less realistic in appearance. As a result, given our reduced familiarity with shrunken body parts, such representations would have been less likely to be incorporated into the body representation.

In order to explore the mechanisms responsible for distorted somatic perception following manipulated representations of perceived own body size, Experiments 1 and 2 used the MIRAGE mediated reality system (Newport, Preston, Pearce & Holton, 2009; University of Nottingham) to create spatially coincident dynamic multisensory illusions that altered perceived hand and index finger size in both directions, creating stretched and shrunken representations of the finger and hand. Experiment 1, examined whether judgements of own body perception were influenced by the nature of the size altering illusions. Participants were instructed to judge veridical (or real) hand and finger size using an online resizing task (by the use of illusory manipulation). Experiment 2 also examined perceived veridical finger size, however using both online and offline (post-illusion) size estimation tasks. Both experiments also examined ownership towards illusory manipulated representations of the body as well as how strongly participants felt each illusion using standard questionnaire methods.

Large individual differences have often been reported in the experience of somatic illusions. For example, the intensity and permanence of illusory arm extension following tendon vibration was found to be higher in extroverts, while neuroticism was positively related with time to evoke the illusion (Juhel & Neiger, 1993). In a later study (Burrack & Brugger, 2005) illusory arm extension was positively associated with tendencies of experiencing body distortions (as measured by the perceptual aberration scale; Chapman, Chapman & Raulin, 1978). These

findings therefore provide a psychological basis for illusion susceptibility and suggest that personality traits are an important mediating factor in such illusory experiences.

In line with these findings, later studies have used such somatic illusions to examine distorted body experiences in clinical populations. For instance, patients suffering from eating disorders (Eshkevari, Rieger, Longo, Haggard & Treasure, 2012), body dysmorphic disorder (Kaplan, Enticott, Hohwy, Castle, Rossell, 2014) and schizophrenia (Thakkar, Nichols, McIntosh & Park, 2011) are likely to experience the RHI more strongly than controls suggesting that such patients may have more flexible body representations. While these patients demonstrate an increased susceptibility to the RHI, individuals with tendencies towards medically unexplained symptoms (MUS) are found to experience the illusion to a lesser extent perhaps due to their increased reliance upon top-down information (such as beliefs, knowledge and expectations) relating to their body (Miles, Poliakoff & Brown, 2011). Tendencies towards MUS are also associated with decreased ownership over veridical and manipulated representations of the limb (Miles et al., 2011: McKenzie & Newport, 2015). Collectively, these experimental studies suggest that such illusions serve as useful objective tools in assessing such disorders and are therefore important in identifying the nature of the distortions in clinical populations. Experiment 3 aimed to explore individual differences in susceptibility to multisensory illusions that alter the perceived shape and size of body parts.

4.2 Experiment 1

In Experiment 1, participants were instructed to judge veridical (or real) hand and finger size using an online resizing task (by the use of illusory manipulation) to examine whether judgements of own body perception were influenced by the nature

of the illusions. If body representation was influenced by the illusions, perceived veridical body size was expected to be updated in the direction of the illusory manipulation; with longer and shorter representations of the finger and hand judged as normal size following illusory stretching and shrinking respectively. Illusion strength and ownership was measured using questionnaires that assessed how strongly participants felt each illusion and how strongly they felt the distorted representations of their finger and hand to belong to them respectively. In line with the findings of Chapter 3, participants were expected experience each illusion strongly and claim ownership over these manipulated representations of their hand.

4.3 Experiment 1 Method

4.3.1 Participants

Thirty seven right-handed (Oldfield, 1971) participants (17 male) aged 18 to 29 years (mean age=21.89; SD=2.67) were recruited. Written informed consent was obtained prior to participation and none of the participants reported any sensory deficits. All procedures were approved by the University of Nottingham Malaysia Campus Research Ethics Committee. Participants were compensated with sweets for their participation.

4.3.2Apparatus and Material

a) Questionnaire measures

As in Chapter 3 the acclimatisation questionnaire (Newport, Pearce & Preston, 2010) assessed sense of ownership towards the video image of the hand in its actual location prior to the illusions when seen through the mirror of the MIRAGE. Illusion strength and ownership questionnaires assessed the extent to which each illusion was

incorporated into participants' body representation (adapted from Preston & Newport, 2012). These questionnaires indicated how strongly participants felt each multisensory illusion and participants' sense of ownership towards the distorted appearance of their finger/hand. In both questionnaires participants made verbal judgements on a 9 point numeric rating scale in which 9 indicated strong illusion strength/ ownership and 1 indicated low illusion strength/ ownership.

b) MIRAGE system

The MIRAGE system (please refer back to a detailed description of this apparatus in Chapter 3) provided participants with real-time video footage of their own hand in its actual location with a delay less than 17ms – a delay found to be behaviourally negligible (Newport et al., 2009; Newport et al., 2010). In the current study, images captured by the camera were manipulated using custom software to create four convincing multisensory illusions; 'stretched finger' 'shrunken finger', 'stretched hand' and 'shrunken hand' (see Figure 4.1a-d). During the stretched illusions, the experimenter grasped and pulled participants' index finger/hand with slight pressure while the image of their finger/hand (seen through the device) was simultaneously seen to grow longer. For the shrunken illusions, participants' finger/hand was gently pushed in with light pressure while the image of the hand was simultaneously seen to grow shorter (see Preston & Newport, 2011). When the finger was being stretched and shrunken the distal end of the index finger (fingertip) was grasped and pulled/pushed while when the hand was stretched and shrunken the dorsal region of the palm was grasped and pulled/pushed.

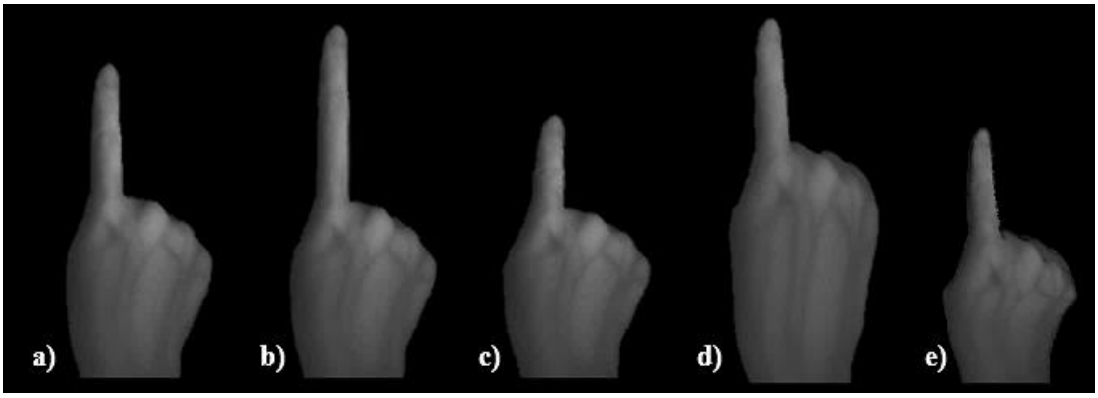


Figure 4.1a-d: Veridical finger length and manipulated length: (a) Veridical condition (no manipulation) (b) Stretched finger (c) Shrunken finger (d) Stretched hand (e) Shrunken hand

4.3.3 Procedure

Upon being seated in front of the MIRAGE system, participants were given a brief period of acclimatisation (~20 seconds) during which time they were encouraged to move both hands within the device in any way they wanted (no systematic instructions were given). This was followed by the 6 item acclimatisation questionnaire. Participants were then instructed to take their left hand out and the first illusion (stretched finger, shrunken finger, stretched hand, or shrunken hand) was conducted in a counter-balanced order on the right hand. As mentioned above, during each illusion, the experimenter either gently pulled or pushed participants' finger/hand while they watched their finger/hand grow longer or shorter than its veridical length. Participants were instructed to keep their hands still during and following each multisensory illusion. After the application of each illusion, the experimenter reached for the participants' finger/hand and asked them whether they felt the touch, with the aim of providing congruent visuo-tactile feedback to indicate that participants were still watching their own hand. Illusion strength and ownership questionnaires corresponding to each multisensory illusion condition were then conducted and took approximately 45 seconds. Participants' judgements of perceived

veridical finger and hand length were then obtained. During this task participants were asked whether this manipulated (stretched/shrunk) finger/hand had to be made longer or shorter to reach its veridical length. The experimenter then grasped and pulled/pushed participants' finger/hand in the direction specified – one unit at a time (units are defined in terms of screen pixels, where 1 pixel=1.5mm). Participants were instructed to say 'stop' when they felt like their finger/hand had reached its veridical length. The stopping point was recorded and used to calculate the percentage increase or decrease in perceived finger length following the illusion. Participants were asked to take their hand out of the MIRAGE system at the end of every illusion condition and allowed to move it to prevent any carryover effects from the previous illusion and reset perceived finger length.

4.4 Experiment 1 Results

4.4.1 Questionnaire responses

Questionnaire ratings were significantly negatively skewed and remained not normally distributed (Shapiro Wilk statistic showed that $p<.05$) despite attempts to transform the data; consequently non-parametric analyses were conducted.

Acclimatisation questionnaire: Responses indicated a strong ownership towards the live video images of the hands. Participants strongly agreed with statements such as *'It seemed like the image of the hand was my own'* (Median = 9) and *'It seemed like the image of the hand belonged to me'* (Median = 8; see Figure 4.2a).

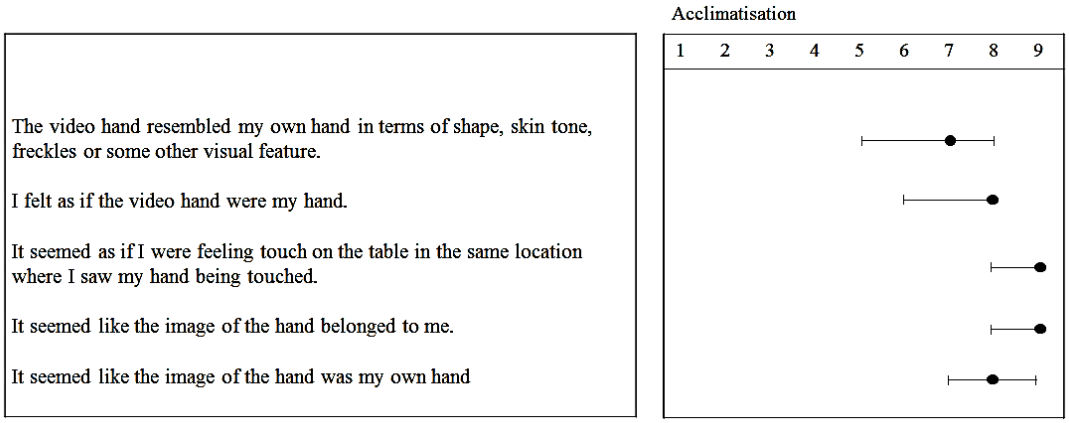
Illusion strength and ownership questionnaires (see Figure 4.3b-c): Responses to the statements *'I felt like my finger/hand was being stretched/shrunken'* and '*I feel like my finger/hand is longer/shorter than normal'* were separately averaged for the

stretched and shrunken finger and hand conditions to obtain mean ratings for illusion strength – that is, the extent to which participants felt each multisensory illusion. Similarly, ratings to the statements *'I feel like I am watching myself'* and *'I feel like the finger/hand I am seeing belongs to me'* were separately averaged for each illusion condition to obtain mean ratings of ownership over the manipulated representations of the finger and hand. Mean ownership ratings indicated that 95% and 89% of participants had ratings of 5 or higher during the stretched and shrunken finger conditions respectively. For illusion strength, 68% of participants had average ratings of 5 or above during the stretched finger condition, while 70% of participants had ratings of 5 and above during the shrunken finger condition.

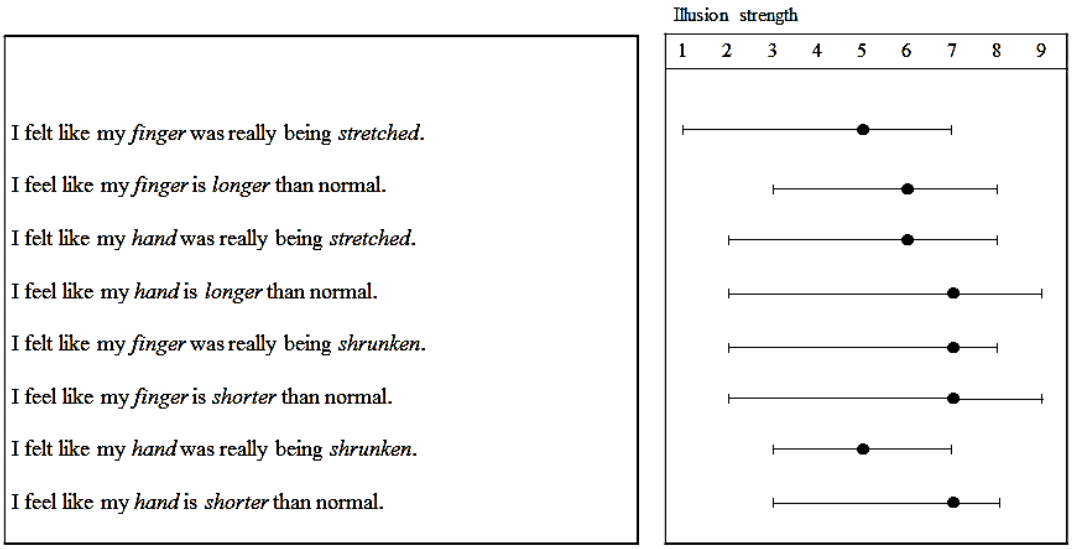
During the stretched hand condition 92% had mean ownership scores of 5 or greater while 86% had mean ownership scores of 5 and above during the shrunken hand illusion condition. Mean illusion strength ratings indicated that 70% of participants had ratings of 5 and above while 73% had mean ratings of 5 and above during the shrunken hand condition. Less than 30% of the sample had scores of the 3 or less in all conditions, demonstrating that a majority of the sample were susceptible to the illusions and claimed strong ownership over their hand and finger regardless of the direction of the distortion.

Mean illusion strength and ownership ratings were then compared across the four conditions. A Friedman's ANOVA revealed no significant differences for mean illusion strength (χ^2 (3, N=37) = 4.00, p=.26) or mean ownership (χ^2 (3, N=37) = 3.18, p.36) across the four conditions.

a) Acclimatisation



b) Illusion strength statements



c) Ownership statements

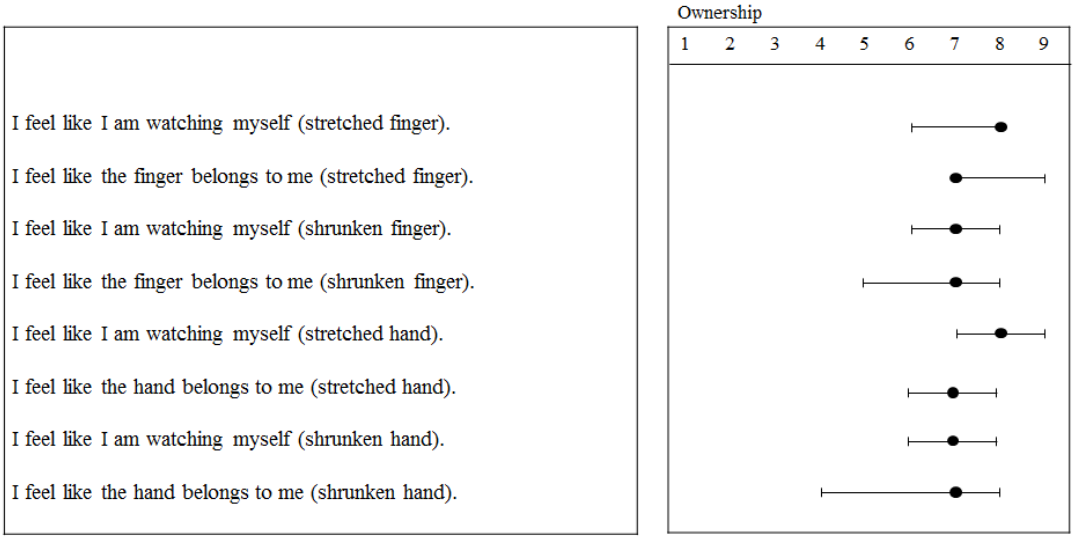


Figure 4.2a-c: Medians and inter-quartile ranges for questionnaire ratings: (a) Acclimatisation (b) Illusion strength ratings (c) Ownership ratings

4.4.2 Judgments of perceived finger length: online resizing

Percentage increase and decrease in finger/hand length from veridical was calculated and used to determine the mean percentage overestimation/underestimation for each participant in all four conditions (see Figure 4.3). Chi square analyses were used to compare the proportion of participants that overestimated or underestimated perceived finger and hand length in each condition to those that did not. Following the stretched finger illusion all participants (100%) overestimated perceived finger length (mean percentage overestimation= 50.99%, SD=19.87) stating that their finger had reached its veridical length when it was still much longer than in reality. 68% of participants (χ^2 (1, N=37) = 4.57, p=.033) underestimated their finger length following the shrunken finger illusion (mean percentage underestimation=55.74%, SD=51.97). All participants (100%) also overestimated perceived hand length following the stretched hand illusion (mean percentage overestimation=39.86%, SD=16.27) while 73% of participants (χ^2 (1, N=37) = 7.81, p=.005) underestimated

the perceived length of their hand following the shrunken hand illusion (mean percentage underestimation=55.40%, SD=40.39). One sample *t*-tests revealed that perceived length overestimated during the stretched finger ($t_{(36)}$=15.06, p<.001, d=2.47) and stretched hand ($t_{(36)}$=14.86, p<.001, d=2.44) conditions as well as the perceived length underestimated during the shrunken finger ($t_{(24)}$=8.14, p<.001, d=1.63) and shrunken hand conditions ($t_{(26)}$=8.81, p<.001, d=1.69) were significantly greater than zero (– veridical finger length).

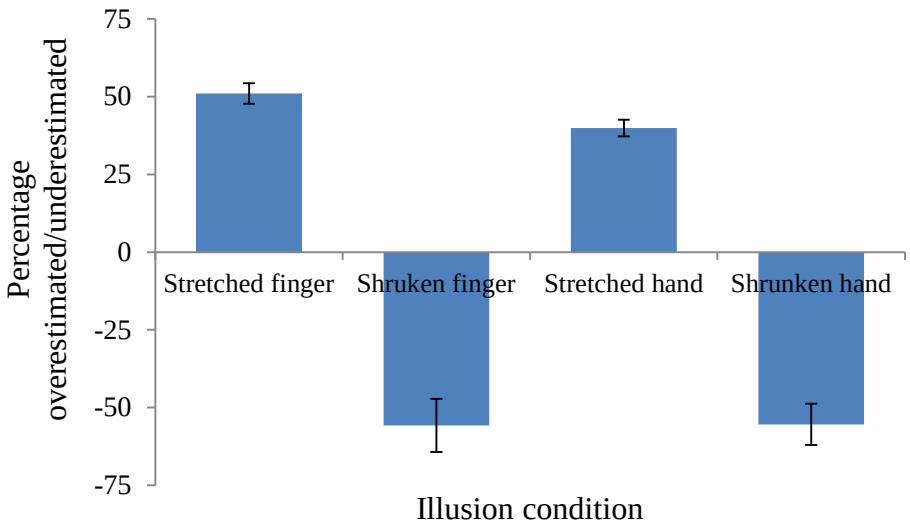


Figure 4.3: Percentage overestimated and underestimated of finger length following illusory manipulations (Error bars show standard error of the mean).

4.5 Experiment 1 Discussion

This study investigated how illusory manipulations of body size altered perceived body representation and the underlying mechanisms. In line with the hypothesis, perceived veridical body size following each multisensory illusion was affected by the nature of that illusion with longer and shorter fingers and hands being judged as veridical length following illusory stretching and shrinking respectively. The findings, therefore, suggest that each illusion may have temporarily altered the

mental representations of the hand and finger. The results also expand upon previous studies that have found shrunken/minified body parts to alter object perception in the external environment (Bruno & Bertamini, 2010; Banakou et al., 2013), by demonstrating that a brief exposure to stretched and shrunken body parts also altered the perceived size of one's own body – therefore, the flexibility of the body representation could perhaps be more bidirectional than previous thought (Pavani & Zampini, 2007; deVignemont et al, 2005). The questionnaire data revealed no significant differences in ownership across the conditions, indicating that ownership was not lost as a result of the multisensory distortions. In fact ownership was claimed over both shrunken illusions, demonstrating ownership towards different body forms (van der Hoort et al., 2011; Banakou et al., 2013). However, it could be argued that rather than reflecting any influence of a 'directional' updating of the body representation, the results of Experiment 1 may be due to participants deciding that the altered body part was returned to veridical size within an acceptable degree of 'normal'; displaying a bias toward saying "stop" early. Alternatively, it could also be that participants were directly influenced by the nature of the illusion when asked to indicate veridical finger length (*e.g.,* state that their finger had to be made shorter following illusory stretching). Therefore, this was addressed in Experiment 2.

4.6 Experiment 2

In order to explore any bias toward simply accepting a distorted body part as 'close enough' to normal, and demonstrate that the multisensory illusions were in fact responsible for changes in perceived finger length and hand size, the current study introduced a stepwise size manipulation following illusory stretching and shrinking. Additionally, given that previous studies have reported discrepancies in perceived

body shape and size with regard to the methods of measurement (Cash & Deagle, 1997; Longo & Haggard, 2012), Experiment 2 also included an additional offline measure of perceived body size that assessed alterations to the body representations post-illusion. For example, perceived body representation is found to be different with depictive tasks (in which shape and size of the body is compared to visual depictions of that body part) and metric tasks (in which body size is compared to a non-body physical standard) in both healthy and clinical populations (Cash & Deagle, 1997; Longo & Haggard, 2012) suggesting that these measures may reflect different aspects of the body representation. Previous virtual reality studies appear to have adopted a form of an online measure when determining somatic perception in the virtual environment, as judgements of object size perception were made during the course of the manipulation which did not necessitate access to stored (offline) body representations. Indeed, offline body representations are thought to be stable and reflect how the body is usually perceived to be. Therefore, while findings in line with Experiment 1 were expected for the online measure, the offline measure was not expected to be influenced by the illusions. As similar response patterns were observed following illusory manipulations of the finger and the hand, Experiment 2 focused solely on illusory stretching and shrinking of the right index finger.

4.7 Experiment 2 Method

4.7.1 Participants

Twenty three right handed (Oldfield, 1971) participants (11 male) aged 18 to 21 years (mean age=19.00; SD=0.77) were recruited. Participants reported no sensory deficits and gave written informed consent prior to participation. Participants were

compensated with RM 5 or 0.5 course credit (psychology students) for their participation.

4.7.2 Apparatus and Material

a) Questionnaire measures

As in Experiment 1, the acclimatisation and illusion strength and hand ownership questionnaires were used to assess the extent to which participants felt ownership over a video image of their hand, as well as how strongly participants incorporated the manipulated representations of their hand into their body representation.

b) MIRAGE system

As in Experiment 1, during the stretched and shrunken finger conditions the experimenter gently pulled or pushed participants' index finger with light pressure while the image of the finger was simultaneously seen to grow longer and shorter respectively (see Figure 4.4).

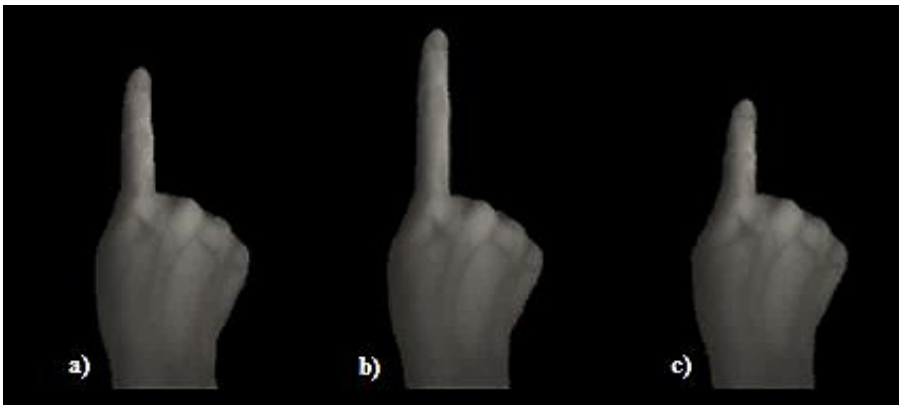


***Figure 4.4a-c**:* Veridical finger length and manipulated length (using multisensory illusions). (a) Veridical finger length (b) Stretched finger (c) Shrunken finger

4.7.3 Procedure

Following a brief period of acclimatisation during which time both hands were viewed to move freely within the MIRAGE system (~ 20 seconds) the acclimatisation questionnaire was administered. Participants were then instructed to take their left hand out and handed a divider tool from a mathematical drawing kit (The Oxford Mathematical set of instruments; Helix-England) and asked to manipulate the distance between the two points (left- handed) until it was felt to match the perceived length of the index finger (-initial length; accuracy 1mm). Although participants could see the hand that was placed within the MIRAGE system, they were encouraged to move the two points of the divider to demonstrate how long they felt their index finger to be (and not what they were seeing) to provide a baseline measurement.

The first visuo-proprioceptive illusion (stretched finger/shrunken finger) was then conducted in a counter-balanced order on the right hand and was followed by corresponding illusion strength and hand ownership questionnaires. Illusion administration was identical to the procedure described in Experiment 1. Following the illusion strength and hand ownership questionnaires, the experimenter used a stepwise manipulation to change the (already manipulated) length of the index finger in the following sequence; stretch- shrink-stretch for half the trials and shrink-stretch-shrink in the remainder. During the stretch-shrink-stretch step-wise manipulation, the altered finger length (*e.g.*, 30 units) was further stretched by half the number of units of the initial altered length [*e.g.*, (30+15) 45 units)], then shrunken by half the number of units of the initial length altered [*e.g.*, (45-30) 15 units)] and stretched again by half the number of units of the initially altered length which brought the finger back to initial manipulated length [*e.g.*, (15+15) 30 units)] and vice-versa for the shrink-stretch-shrink manipulation (see Figure 4.5 for example). At each point during the

stepwise manipulation the experimenter reached and touched the tip of the finger ensuring congruency in what participants felt and saw. The stepwise manipulation was followed by veridical finger length judgements. As in Experiment 1, participants indicated whether their finger had to be made longer or shorter to reach its veridical length, while the experimenter altered perceived finger length in the direction specified. The stopping point was recorded and used to calculate the percentage increase or decrease in perceived finger length following each illusion. To further examine the effectiveness of the illusion, all participants were again handed the divider tool and asked to judge the size they felt the real length of their finger to be following each illusion, thus providing an offline measure of perceived body size[1]. Each illusion was repeated three times for each participant, and participants were asked to take their hand out of the MIRAGE system at the end of every trial to reset perceived finger length. As each illusion was repeated three times, illusion strength and ownership statements were presented in a randomised order in every trial.

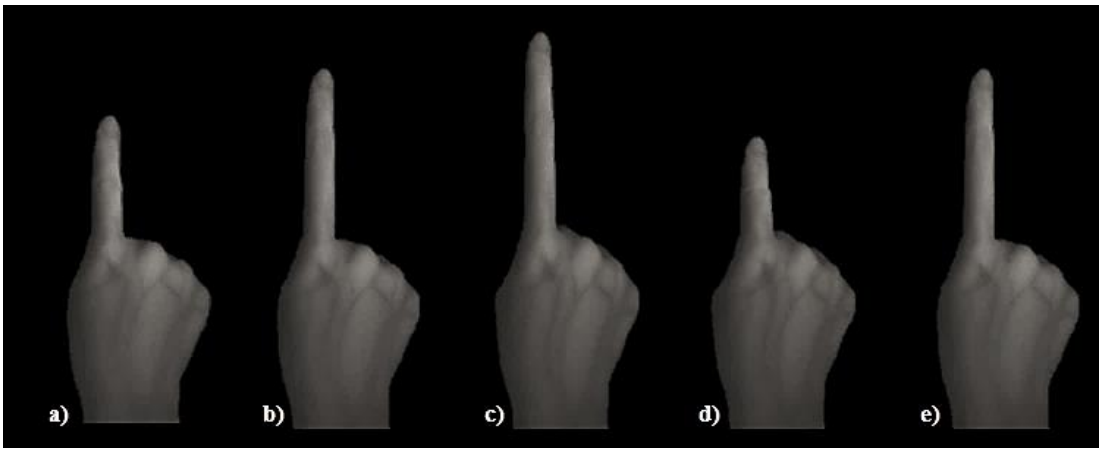


Figure 4.5a-e: Altering perceived finger length following illusions (stretch-shrink-stretch). (a)Veridical length (b) Initial stretched length (c) Stretched to half the number of units of the initial stretching (d) Shrunken to half the number of units of the initial (e) Brought back to initial length stretched

[1] The divider was handed with the two points closed. During the offline body size estimates, participants were asked to estimate how long they felt their finger to really be as opposed to what they were seeing.

4.8 Experiment 2 Results

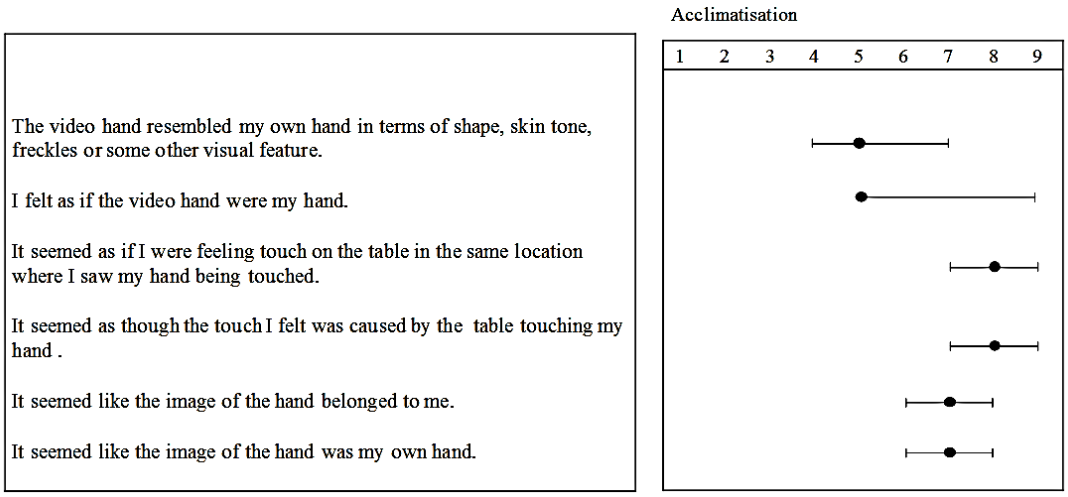
4.8.1 Questionnaire responses

Acclimatisation questionnaire: Responses indicated strong ownership towards the live video images of the hands. Participants strongly agreed with statements such as *'It seemed like the image of the hand was my own'* (Median= 8) and '*It seemed like the image of the hand belonged to me'* (Median=7). Acclimatisation scores were not normally distributed and remained so following attempts to transform the data (Shapiro Wilk statistic showed that $p<.05$), Figure 4.6a therefore represents the medians and interquartile ranges for each statement.

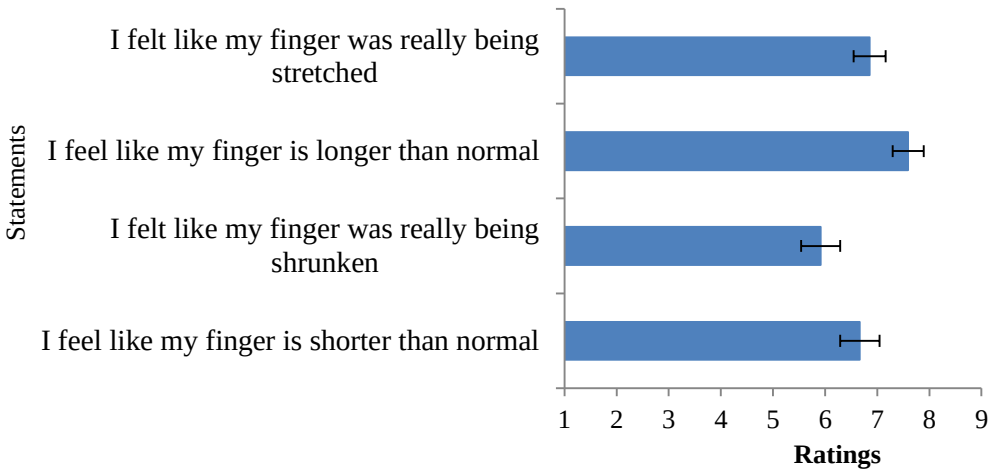
Illusion strength and ownership questionnaires: Ratings indicated that participants felt their finger to be stretched or shrunk but still claimed ownership over these manipulated representations of the finger (see Figure 4.6b-c). As in Experiment 1, responses to the statements *'I felt like my finger was being stretched/shrunken'* and *'I feel like my finger is longer/shorter than normal'* were separately averaged for the stretched and shrunken finger conditions to obtain mean ratings for illusion strength. Ratings to the statements *'I feel like I am watching myself' and 'I feel like the finger I am seeing belongs to me'* were separately averaged for both illusion conditions to obtain mean ratings of ownership. During the stretched finger condition, 96% of participants had average ratings of 5 or above for illusion strength, while 83% of participants had ratings of 5 and above during the shrunken finger condition. Mean ownership ratings indicated that 70% and 74% of participants had ratings of 5 or higher during the stretched and shrunken finger conditions respectively. Less than 15% of the sample had scores of 3 or less in all conditions. Most participants therefore reported feeling each illusion and retained ownership over distorted representations of their finger. Although no difference between the stretched (Mean = 6) and shrunken

(Mean = 6) conditions was seen for mean ownership ratings ($t_{(22)}$=.813, p=.43), comparing mean illusion strength statements revealed that stretching (Mean =7) was felt more strongly than shrinking (Mean = 6; $t_{(22)}$=.4.2, p<.001; d=.74).

(a) Acclimatisation



(b) Illusion strength statements



(c) Ownership statements

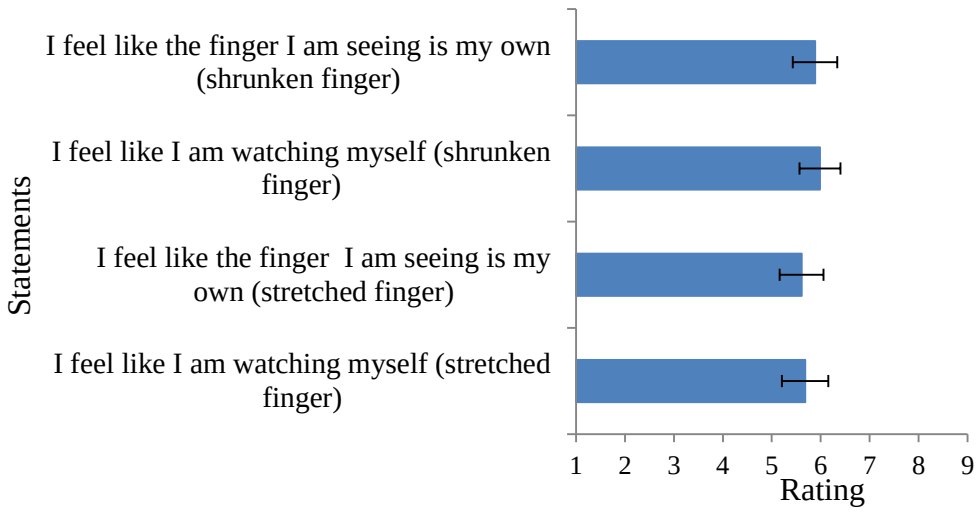


Figure 4.6a-c: (a) Medians and inter-quartile ranges for questionnaire ratings for Acclimatisation. (b) Mean ratings for illusion strength and (c) ownership ratings for stretched finger and shrunken finger illusions. Error bars represent standard error of the mean.

4.8.2 Judgments of perceived finger length: online resizing

Percentage increase or decrease in finger length from veridical was calculated and used to determine the mean percentage of finger length overestimated/underestimated for each participant in both conditions (see Figure 4.7). Chi square analyses were used to compare the proportion of participants that overestimated or underestimated perceived finger length in each condition separately. Following the stretched illusion 96% of participants (χ^2 (1, N=23) = 19.17, p<.001) overestimated finger length (mean percentage overestimation= 45.17%, SD=26.29) stating that their finger had reached its veridical length when it was still much longer than in reality. Similarly, 91% of participants (χ^2 (1, N=23) = 15.70, p<.001) underestimated their finger length following the shrunken illusion (mean percentage underestimation=54.63%, SD=41.45). One sample t-tests revealed that perceived

length overestimated ($t(21)=8.98$, $p<.001$, $d=1.91$) and underestimated ($t(21)=10.87$, $p<.001$, $d=2.32$) was significantly greater than zero (- veridical finger length).

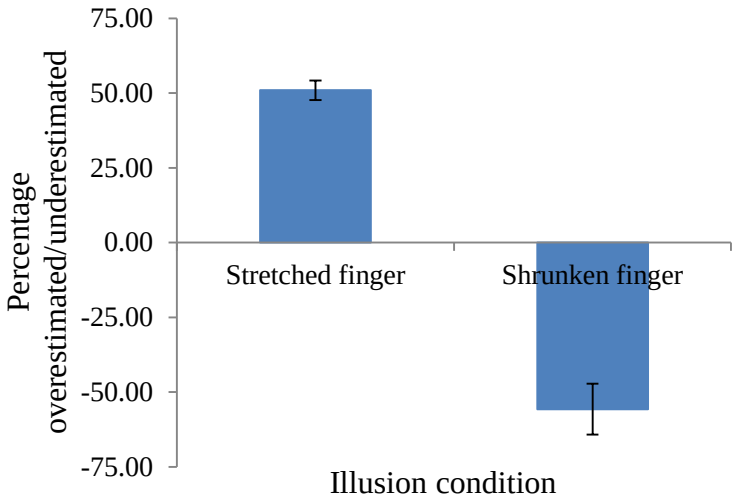


Figure 4.7: Percentage overestimated and underestimated of finger length following illusory manipulations (Error bars show standard error of the mean).

4.8.3 Judgments of perceived finger length: offline size estimation

Chi square analyses were again used to determine the proportion of participants that overestimated perceived real finger size following the stretched and shrunken illusions compared to the initial length. 61% of participants overestimated perceived finger length compared to perceived initial finger length during the stretched illusion; however, this was not found to be significant ($\chi 2$ (1, N=23) = 1.09, p=.30; mean percentage overestimation= 17.23%, SD=13.63; mean length overestimated=11.9 mm). During the shrunken illusion however, 83% of participants underestimated perceived finger length ($\chi 2$ (1, N=23) = 9.78, p=.002; mean percentage underestimation = 84.23%, SD=11.01; mean length underestimated=13.9 mm). Next, perceived length overestimated and underestimated was compared to *perceived initial length*. Perceived length following shrinking was found to be significantly shorter than perceived initial length ($t_{(22)}=4.46$, $p<.001$, $d=.64$), however,

no difference between initial perceived length and perceived length following the stretched illusion was seen ($t_{(22)}$=1.70, p=.104).

In addition, we also examined the association between percentage overestimation and underestimation for the two estimation tasks. Online and offline tasks were not correlated for percentage overestimation ($r_{(23)}$=-.048, p=.83) or percentage underestimation ($r_{(23)}$=.34, p=.11) in perceived finger length, suggesting that the two tasks were in fact independent.

4.9 Experiment 2 Discussion

In Experiment 2, we investigated how somatic representations were altered following manipulations to perceived body size using both online and offline measures of perceived body size as well as subjective ratings of illusion susceptibility and body ownership. As in Experiment 1,during the online task, perceived finger size was influenced by the nature of the illusion with longer and shorter representations of the finger being judged as veridical length following illusory stretching and shrinking in over 90% of the sample. However, the offline size estimation task only altered perceived veridical body size following the shrunken illusion, suggesting differences between various methods of measurement. Indeed, no significant associations between online and offline measures were evident for overestimations and underestimations of perceived finger length. Although, these findings may not provide definitive evidence, the findings are consistent with the idea that online and offline size estimation tasks assess different aspects of the body representation – *i.e.*, current perceptions of the body that are updated through incoming sensory input and stored perceptions of the body representation respectively. The decrease in perceived body size for the offline measure nevertheless provides evidence suggesting that stored body representations may also be distorted, the reasons for which are addressed in the

general discussion. The questionnaire items demonstrated that the stretched illusion was felt more strongly compared to the shrunken. However, ownership ratings towards both manipulated representations of the finger were strong and no significant differences were observed for sense of ownership between the two conditions indicating that ownership was not lost as a result of the distorted appearances of the hand. These findings therefore add to and extend recent studies, including Experiment 1, that have shown ownership towards both larger (Kilteni, Normand, Sanchez-Vives & Slater, 2012) and smaller (van der Hoort et al., 2011) representations of the body. This study also provides evidence for the bidirectional flexibility of the internal body representation.

4.10 Experiment 3

Large individual differences have been demonstrated in participants' responsiveness to illusory sensations, with personality traits (Juhel & Neiger, 1993), proneness to body schema related distortions (Burrack & Brugger, 2005) and tendencies towards medically unexplained symptoms (Miles et al., 2011) being associated with illusion susceptibility. This study therefore aimed to extend previous findings by exploring individual differences in susceptibility to multisensory illusions that altered the perceived shape and size of body parts. Previously, such illusory manipulations have been found to temporarily reduce pain evoked by movement in patients with complex regional pain syndrome (CRPS; Moseley, Parsons, & Spence, 2008) and also temporarily alleviate pain in patients with osteoarthritis (Preston & Newport, 2011). Changes in brain function is commonly reported in chronic pain states, therefore pain relief in these cases is thought to arise from normalising cortical reorganisation as a result of the illusions/manipulations (Moseley et al., 2008;

McCabe, 2011; Preston & Newport, 2011). Moreover, manipulating apparent body shape and size using virtual reality has been found to reduce binge eating habits and anxiety, as well as increase body satisfaction, self-acceptance and self-esteem in patients suffering from eating disorders (Riva, Bacchetta, Baruffi & Molinari, 2002; Riva, Bacchetta, Cesa, Conti & Molinari, 2003; Ferrer-García & Gutiérrez-Maldonado, 2012; Aimé, Cotton, Guitard & Bouchard, 2012). Such somatic manipulations are relatively free from cognitive contamination and, identifying individuals who may be most susceptible to these manipulations is useful in the development of therapeutic illusory exercises aimed at correcting misperceptions in patients suffering from distorted body representations.

The somatosensory amplification scale (SSAS; Barsky et al., 1990) is a well-established indicator of heightened somatosensory sensitivity (Nakao & Barsky, 2007); with patients suffering from various forms of chronic pain states (Barsky et al., 1999; Gregory et al., 2000; Gregory et al., 2005) and eating disorders such as anorexia nervosa (Sagardoy et al., 2015) reporting higher scores on this scale. Experimental and epidemiological studies have revealed somatosensory sensitivity assessed using the SSAS to reflect a trait-like phenomenon (Nakao & Barsky, 2007) that is distributed among normal (Nakao, Barsky, Kumano & Kuboki, 2002; Nakao, Tamiya & Yano, 2005; Nakao, Barsky, Nishikitani, Yano & Murata, 2007) and clinical populations (Nakao et al.., 2002). The current study therefore examined the relationship between SSAS scores and susceptibility to multisensory illusions (measured via illusion strength ratings) that involve alterations to the perceived shape and size of the body. Positive correlations between SSAS scores and susceptibility to the multisensory illusions would suggest that the SSAS is indicative of individuals most susceptible to illusory manipulations of body size.

The intensity of various somatic illusions has been found to be stronger in females (Burrack & Brugger, 2005). Moreover, most chronic pain states as well as eating disorders are more commonly reported in females (Linkenauger, Lewinsohn, Seeley, Moerk & Striegel-Moore, 2002; Rustøen et al., 2004; Striegel-Moore et al., 2009). This study therefore also examined differences in illusion susceptibility, SSAS scores and the association between the two in males and females (Nakao, et al., 2005). Based on previous findings, females were expected to be more susceptible to the illusions, have higher SSAS scores and show a stronger association between the two.

4.11 Experiment 3 Method

4.11.1 Participants

Forty four right handed (Oldfield, 1971) participants (22 male) aged 18 to 27 years (mean age=19.84; SD=1.84) were recruited. Participants reported no sensory deficits and gave written informed consent prior to participation. Participants were compensated with RM 5 or 0.5 course credit (psychology students) for their participation.

4.11.2 Apparatus and Material

a) Questionnaire measures

In addition to the acclimatisation and illusion strength and hand ownership questionnaires used in Experiments 1 and 2, participants also responded to the somatosensory amplification scale (SSAS; Barsky, Wyshak & Klerman, 1990) and the trait scale of the state-trait anxiety inventory (STAI-T; Spielberger, Gorssuch, Lushene, Vagg & Jacobs, 1983).

The Somatosensory amplification scale: The Somatosensory amplification scale (SSAS; see appendix 3.1 for questionnaire; Barsky et al., 1990; Nakao & Barsky, 2007) measures tendencies towards experiencing somatic sensations as being intense, noxious and disturbing. Such tendencies have previously been found to be associated with hypochondriasis, depression, anxiety as well as a variety of other medical conditions including chronic pain states (Barsky & Wyshak, 1990; Barsky et al., 1999; Gregory, Manring & Berry, 2000; Gregory, Manring & Wade, 2005) and eating disorders (Sagardoy et al., 2015) in which the body representation is distorted. The SSAS was therefore used to examine individual predispositions towards such states. The scale consists of 10 statements about unpleasant bodily events including 'sudden loud noises really bother me' and 'I hate to be too hot or too cold'. Participants rated the degree to which each statement related to them a Likert scale ranging 1 (not at all true) to 5 (extremely true). The total score range is therefore between 10 and 50. The questionnaire has an internal consistence of .70 and a test-retest reliability of .85 (Barsky et al., 1990).

State-trait anxiety inventory- Trait scale: The Trait scale of the State-trait anxiety inventory (STAI-T; see appendix 3.2 or questionnaire; Spielberger et al., 1983) represents a predisposition to react with anxiety in stressful situations. The STAI-T consisted of 20 self-report items assessing trait affect. Negative affect has often been found to be associated with unpleasant and distorted somatic experiences (Watson & Pennebaker, 1989; Gaskin, Greene, Robinson & Geisser, 1992) including physical symptoms and amplified somatic sensations (Watson & Pennebaker, 1989; Köteles, Szemerszky, freyler & Bárdos, 2011). The STAI-T has previously been found to be associated with such effects (Watson & Pennebaker, 1989; Köteles et al., 2011) and was therefore included as a covariate in the current experiments to control

for such effects. The scale contained statements such as ‘I feel calm’, ‘I feel frightened’ and asked participants make their responses on a 4 point Likert scale; 1 (almost never) and 4 (almost always). The total scores therefore range from 20 to 80. The trait scale of the STAI has been found to be stable across changes in stress in students and has a validity coefficient of .82 (Martuza & Kallstrom, 1974) while test-retest reliability coefficients were found to range between .65 and .75 (Spielberger, 1989).

b) MIRAGE system

As in Experiment 2, during the stretched and shrunken finger conditions the experimenter gently pulled or pushed participants’ index finger with light pressure while the image of the finger was seen to grow longer and shorter respectively.

4.11.3 Procedure

Participants were initially given a brief period of acclimatisation (~ 20 seconds) followed by the acclimatisation questionnaire. The first visuo-proprioceptive illusion (finger stretched/finger shrunken) was then conducted in a counter balanced order on the right hand. During each illusion the experimenter either gently pulled or pushed participants’ finger while they watched their finger grow longer or shorter than its veridical length. This was followed by the illusion strength and ownership questionnaire corresponding to that condition. At the end of each trial participants took their hand out of the MIRAGE system to prevent any carryover effects.

4.12 Experiment 3 Results

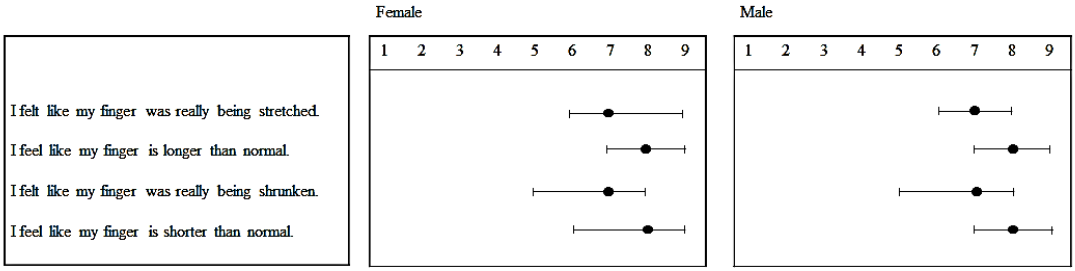
4.12.1 Questionnaire measures

All questionnaire ratings were significantly negatively skewed and remained so following transformation (Shapiro Wilk statistic showed that $p<.05$), therefore non-parametric analyses were used.

Acclimatisation questionnaire: Overall responses indicated ownership towards the live video images of the hands. Participants strongly agreed with statements such as *'It seemed like the image of the hand was my own'* (Median= 8) and *'It seemed like the image of the hand belonged to me'* (Median=7).

Illusion strength and ownership questionnaires: Illusion strength and hand ownership responses for each condition were separately examined for males and females (see Figure 4.8a-b). As in Experiments1 and 2, mean illusion strength and hand ownership ratings for the two illusion conditions were separately compared. Whereas no significant difference in mean ownership between the stretched (Median = 6) and shrunken (Median = 6) conditions were seen (Z= .89, p=.38), illusion strength was found to be stronger in the stretched (Median = 8) compared to the shrunken condition (Median = 7; Z= 3.22, p=.001, r=.49). No significant differences were seen between males and females for mean illusion strength during the stretched (U= 207.5, p=.42) or shrunken (U=224.5, p=.68) finger conditions. There were also no significant gender differences in ownership during the stretched (U= 216.0, p=.54) or shrunken (U= 213.0, p=.50) condition. Therefore, the illusory manipulations did not differently influence male and female participants.

a) Illusion strength statements



b) Ownership statements

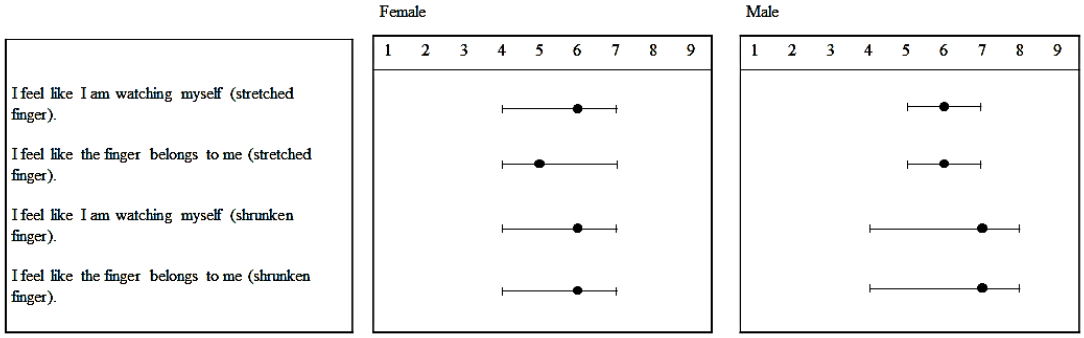


Figure 4.8a-b: Medians and inter-quartile ranges for questionnaire ratings for males and females: (a) Illusion strength ratings (b) Ownership ratings

4.12.2 Association between SSAS scores and illusion strength and ownership ratings

When controlling for STAI-T; the overall association between SSAS scores and mean illusion strength ratings was not significant for the stretched illusion ($r_{(41)}$=.203, p=.19) or shrunken illusion ($r_{(41)}$=.27, p=.079). The overall association between SSAS and ownership over the manipulated representations of the finger were also not significant for either the stretched ($r_{(41)}$=.046, p=.77) or shrunken ($r_{(41)}$=.104, p=.51) finger conditions when controlled for STAI-T.

No significant gender differences were found for SSAS scores ($t_{(42)=.}$78, p=.44). Interestingly, partial correlations (controlling for STAI-T) showed SSAS scores to be significantly associated with mean illusion strength ratings during the stretched finger illusion ($r_{(19)}$=.47, p=.031) for females (see Figure 4.9), however, this

association failed to reach significance for the shrunken finger illusion ($r_{(19)}$=.38, p=.089). In contrast, no significant associations between illusion strength and SSAS scores for the stretched ($r_{(19)}$=.058, p=.803) and shrunken ($r_{(19)}$=.19, p=.41) conditions were seen for males. Mean ownership was not found to be associated with SSAS scores in the stretched ($r_{(19)}$=.083, p=.72) or shrunken ($r_{(19)}$=.33, p=.15) conditions for females. Similarly, no association between SSAS and ownership was seen for males during the stretched ($r_{(19)}$=.025, p=.91) and shrunken ($r_{(19)}$=-.083, p=.72) finger illusions.

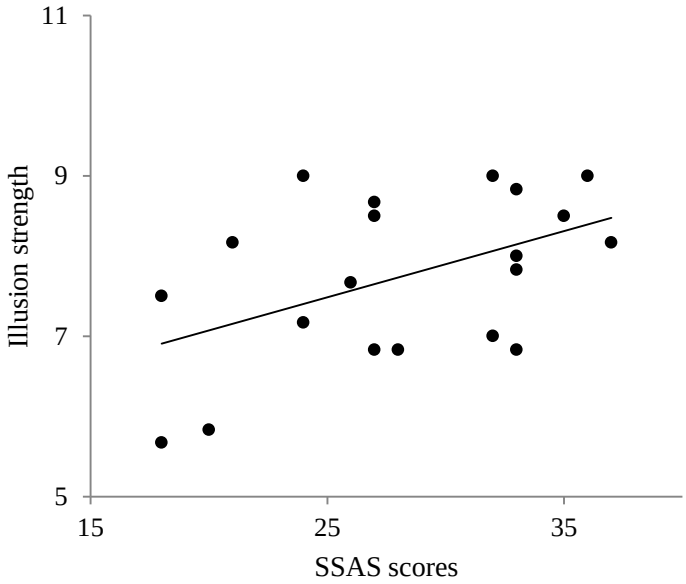


Figure 4.9: Scatter plot displaying the association between SSAS scores and stretched illusion strength ratings for females

4.13 Experiment 3 Discussion

This study examined individual differences in susceptibility to multisensory illusions. Males and females were not found to be differently sensitive to the illusions or report differences in somatosensory sensitivity. Nevertheless, self-reported somatosensory sensitivity scores were significantly associated with illusion strength

during the stretched condition for females. While this finding is interesting in that it demonstrates increased flexibility of the body representation in females displaying greater somatic sensitivity, it also suggests that this effect is sensitive to the nature of the manipulation induced. The current results also revealed no significant association between SSAS scores and ownership for males or females, suggesting both males and females may perhaps maintain similar levels of ownership over distorted body representations. The association between illusion susceptibility and SSAS scores for females links to a broader body of literature that has found links between somatic amplification and somatic symptoms (Köteles & Simor, 2011) as well as eating disorders (Sagardoy et al., 2015). Therefore, participants' self-reported somatic sensitivity may act as a predictor of their susceptibility to illusory body elongation, which may in turn also be indicative of individuals who are most likely to benefit from illusion therapy following distorted perceptions of the body (*e.g.*, chronic pain, eating disorders).

4.14 General discussion

Over three experiments, participants were made to feel that their hand and/or index finger was a different length compared to veridical finger/hand length, using visuo-proprioceptive illusions. All three experiments indicated that ownership was not lost as a result of the illusory manipulations. Although the questionnaire items of Experiments 2 and 3 demonstrated differences between the stretched and shrunken conditions, illusion strength ratings in both experiments were above the mid-value of 5 suggesting that participants felt each illusory manipulation and were susceptible to the illusions. No significant differences in ownership were observed and overall ratings indicated that participants felt the distorted representations of their hand to

belong to them, regardless of the direction of the distortion. Findings of these studies also contradict early fake/rubber hand illusion studies that have shown asymmetric tendencies of ownership towards only larger representations of the body (Pavani & Zampini, 2007; Haggard & Jundi, 2009) and suggest that ownership is readily claimed over dynamic representations of own body parts even when reduced in size, perhaps due to its increased ecological validity and realistic appearance. This highlights the need to use realistic and dynamic measures when determining body ownership following manipulations to body size.

Judgments of perceived finger and hand lengths during the online re-sizing task in Experiments 1 and 2 indicated that perceived body representation was strongly affected by the nature of the illusions, with longer and shorter hands/fingers being judged as veridical (or real) length following visuo-proprioceptive stretching and shrinking respectively. These findings extend recent research that has reported ownership towards shrunken hands and bodies to have a scaling effect on the immediate environment (Bruno & Bertamini, 2010; Linkenauger et al., 2013; Banakou et al., 2013). The fact that perceived body representation was influenced by the nature of the illusion also suggests that the stretched and shrunken illusions may have altered the mental representation of the body part, and extends previous virtual reality studies by providing direct evidence for the spontaneous flexibility of the body representation without the need for scaling techniques.

When asked to indicate the perceived length of the finger using the divider (in Experiment 2), the difference between perceived initial length (prior to the illusions) and perceived length following illusions was only significant for the shrunken condition. This finding highlights differences between both online and offline methods of measurement. While online measures provide estimates of the body

representation in its current form and is updated based on incoming sensory information, offline measures provide estimates of the typical perception of the body representation and is therefore thought to be relatively stable (Carruthers, 2008). Perceived underestimation of finger length may therefore indicate that responses were again affected by nature of the illusion, thus suggesting that the mental representation of the body part was updated following the multisensory illusions. The absence of significant differences between perceived initial length and perceived length following stretching may suggest that offline body representation measures might have been stronger following illusory stretching, compared to shrinking. This could be because the long-term cortical representation of the body that evolves through development contains information relating to the shape and size of the body until it reaches adult size (O'Shaughnessy, 1995; Melzack, Israel, Lacroix & Schultz, 1997). As offline measures represent stored body representations, it may have prevented any significant overestimations in size following illusory stretching. In line with these findings; previous studies have also reported differences in perceived body shape and size with respect to the method of measurement in healthy and clinical populations (Cash & Deagle, 1997; Longo & Haggard, 2010, 2012).

Manipulating perceived body size has also been found to modulate pain perception in patients suffering from both acute and chronic pain. For example, visual enhancement of hand size increases analgesia for experimentally induced acute pain but reduces analgesic effects following reduced hand sizes (Mancini, Longo, Kammers & Haggard, 2011). In contrast, both increasing and decreasing the perceived size of painful body parts results in temporary analgesic effects for osteoarthritis (Preston & Newport, 2011) while ratings of intensified pain and swelling evoked by movement in patients with complex regional pain syndrome was

found to increase when the affected body part was enlarged, however, this increase in pain was less when the viewed limb size was reduced (Moseley et al., 2008). Pain relief through resizing perceived body size is thought to be a result of one of two mechanisms, either the distorted body appearances resulting in disownership of the painful body part, or normalising cortical reorganisation (Moseley et al., 2008; McCabe, 2011; Preston & Newport, 2011). Given that participants felt the manipulated representations of their hand/finger to belong to them, our studies help rule out the latter and suggests that pain relief in these studies may in fact be due to alterations to the somatosensory areas (Schaefer, Flor, Heinze, and Rotte, 2006; Schaefer et al., 2007; Schaefer, Heinze & Rotte, 2008) and increased corrective sensory input to these regions. Furthermore, interoceptive sensitivity has been found to be associated with malleability of body representations such that reduced awareness of interoceptive sensations correlates with stronger ownership over fake body parts (Tsakiris, Tajadura- Jiménez & Costantini, 2011). Ownership over the manipulated representations of the hand/finger in the current studies may therefore be a valuable indicator of internal bodily sensations which may be useful in identifying individuals with tendencies towards disrupted somatic awareness.

Experiment 3 investigated individual differences in susceptibility to visuo-proprioceptive stretching and shrinking of the finger. We found an association between susceptibility to illusory finger elongation and somatosensory sensitivity for females but not males. Females have been suggested to use both internal (visceral/ somatic) and external (situational) cues in somatic judgements and may therefore provide more accurate accounts of their somatic sensations/symptoms (Pennebaker & Roberts, 1992; Pennebaker, 1995). As a result, female SSAS scores might have been more accurate representations of their somatosensory sensitivity. Moreover, females

are also more likely to acknowledge somatic dysfunctions compared to males and also display differences in the perception and appraisal of somatic perception (Barsky et al., 2001) which would have been reflected in their illusion strength scores. As a result, females are seen to be more prone to disorders that involve distorted body images such as eating disorders (Hudson, Hiripi, Pope & Kessler, 2007) and chronic pain states such as CRPS (Sandroni, Benrud-Larson, McClelland & Low, 2003). Such tendencies in females could have led to the observed association between SSAS and illusion susceptibility. This finding provides a link between self-reported somatic sensitivity and susceptibility to somatic illusions in females and suggests that those with increased somatic sensitivity may have more flexible body representations. The SSAS could therefore be useful in identifying individuals with distorted body representations who might in fact be more responsive to illusory treatment (Riva et al., 2002; 2003; Moseley et al., 2008; Preston & Newport, 2011; Ferrer-García & Gutiérrez-Maldonado, 2012; Aimé et al., 2012).

In conclusion, following multisensory distortions applied to participants' own body, the current studies found mental body representations to be rapidly and directly updated to reflect the nature of the distortion. Importantly, ownership was retained over all representations of the body. The ability to retain ownership over distorted somatic representations is important in treating a range of clinical conditions in which the identity and integrity of the body have been compromised. Finally, the SSAS was found to be an indicator of experimentally induced somatic distortions. Future investigations should consider relationships between other factors (such as the big five personality traits) and illusion susceptibility as this would aid the development of targeted intervention programs that cater to a range of patients. Given these findings of altered perceptions of body size following the size altering illusions, Chapter 5

aimed to examine whether such manipulations may alter somatic sensations and the underlying mechanisms using a near threshold tactile detection task.

CHAPTER 5

INVESTIGATING THE EFFECTS OF MULTISENSORY DISTORTIONS OF THE HAND ON NEAR THRESHOLD TACTILE PERCEPTION

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Abstract

Previous research has suggested that altering the perceived shape and size of the body significantly affects perception of somatic events. The studies in the current chapter investigated how multisensory illusions applied to the body altered tactile perception, using the Somatic Signal Detection Task (SSDT; Lloyd et al, 2008). Over three experiments healthy volunteers were asked to report the presence or absence of near threshold tactile stimuli delivered to their index finger during a series of multisensory illusion conditions as well as a veridical-baseline condition (with no illusion). Both increasing and decreasing perceived finger size (at the site of stimulation) improved correct tactile perception, through differing underlying mechanisms. Tactile detection was also improved when perceived hand size (away from the site of stimulation) was altered in either direction and similar processes were found to be responsible for this improvement. During a 'detached' condition, in which the tip of the index finger appeared to be disconnected from the rest of the finger, incorrect touch reports ('false alarms') were reduced, possibly due to reduced tactile noise as a result of attention being directed to the tip of the finger only. These findings suggest that tactile perception following distorted somatic representations varies,

based upon the site of manipulation and provide a link between perceived body representation and somatosensory decision making. Given that false-alarms on the SSDT have been found to closely mimic medically unexplained symptoms (MUS), Experiment 3 also examined the link between false-touch reports and tendencies towards MUS. Results indicated false-alarms to be the most significant predictor of MUS and provided a link between the two in line with proposed clinical models.

5.1 Introduction

The human brain integrates information from the senses to form a stable percept of the body and surrounding objects. On most occasions, this information is effectively coordinated to produce a coherent image of our sensory environment; although, there are instances in which this information is misinterpreted, resulting in a mismatch between reality and our somatic experiences. For example, many amputees continue to experience vivid sensations (including pain) from their amputated limb (Ramachandran & Hirstein 1998), while poor tactile acuity is reported in patients suffering from chronic pain states such as complex regional pain syndrome (CRPS) and knee osteoarthritis (Moseley, Zalucki & Wiech, 2008; Moseley & Wiech, 2009; Stanton et al., 2013).

Experimentally induced somatic illusions have shown that even healthy individuals can misinterpret bodily events through relatively simple cross-modal manipulations. For instance, in the ‘parchment skin’ illusion (Jousmäki & Hari, 1998), skin texture is felt to change when participants rub their hands together in synchrony with a grating sound, while in the ubiquitous rubber hand illusion (Botvinick & Cohen, 1998), watching a fake rubber hand being stroked in synchrony with one’s unseen real hand creates a feeling of ownership towards the rubber and

remaps the felt position of the real hand towards the location of the rubber hand. Additionally, illusory touch in the absence of any tactile stimulation is frequently reported on the somatic signal detection task (SSDT; Lloyd, Mason, Brown & Poliakoff, 2008). This task involves detection of near threshold vibrations (present in 50% of trials) in the presence and absence of a simultaneously presented light. In neurologically healthy participants, the light enhances correct detection of the vibration when it is present, and increases the number of false touch reports in vibration absent trials (Lloyd et al., 2008). Performance on this task has been found to be altered by simple perceptual factors, for example; significantly more light-present illusory touch reports are made when vision of the hand is available compared to when it is not, perhaps due to the light directing tactile attention toward the hand (Mirams, Poliakoff, Brown & Lloyd, 2010). Visual modulation of touch is also dependent on particular measures of tactile judgment; viewing the stimulated hand has been found to increase tactile acuity in two-point discrimination tasks in healthy individuals (Kennett, Taylor-Clarke & Haggard, 2001; Taylor-Clarke, Kennett & Haggard, 2004) and in patients suffering from somatosensory deficits (Serino, Farnè, Rinaldesi et al., 2007), whereas non-informative vision of the stimulated body part has been found to impair detection and discrimination of simple near threshold tactile stimuli, but to enhance discrimination between above threshold tactile stimuli (Harris, Arabzadeh, Moore, & Clifford, 2007).

Manipulating the perceived shape and size of the body has also been found to further alter tactile judgements. For instance, whilst visually attending to the hand reduces two-point discrimination thresholds, magnifying the stimulated hand has been found to further improve this effect (Kennett et al., 2001). In line with this finding, de Vignemont, Ehrsson and Haggard (2005) showed that illusory elongation of perceived

finger length significantly increased the perceived distance between two simultaneous tactile contacts. Manipulations of perceived body (part) size has also been found to alter haptic judgements, such that an object is judged to be larger following enlargement of perceived hand size and vice-versa for 'reduced' hand sizes (Bruno & Bertamini, 2010). Interestingly, alterations made to perceived body size have different modulatory effects on chronic and acute pain. Visual enlargement has been found to enhance analgesia in acute pain (Mancini, Longo, Kammers & Haggard, 2011) and increase pain and swelling (evoked by movement) in chronic pain (Moseley, Parsons, & Spence, 2008) whereas the opposite trend is seen following a decrease in perceived body size. Manipulating the perceived size of painful body parts through multisensory illusions has been found to have strong analgesic effects in patients with osteoarthritis (Preston & Newport, 2011). Collectively these findings suggest that both touch and pain can be modified by manipulated representations of perceived body size.

While most previous studies have investigated how changing the perceived size of a stimulated body part affects tactile detection on tasks with a spatial component, it is as yet unclear whether the reported effects are due to changes in response criterion or increased tactile sensitivity. The aim of the current studies was therefore to investigate how multisensory illusions applied to the hand would affect simple near threshold tactile perception using the SSDT (Lloyd et al., 2008) as it allows us to determine whether a particular manipulation affects tactile perception via changes in tactile sensitivity, or by altering response criterion.

5.2 Experiment 1

Although previous studies have reported increased tactile acuity following visual enlargement of perceived body size (Kennett et al., 2001; de Vignemont et al., 2005), these studies have only focused on perceived enlargement of body size at the site of stimulation. It therefore remains to be investigated whether these reported effects are due to an enlargement of perceived body size at the site of stimulation or a general increase in perceived size of the stimulated body part. We investigated this in Experiment 1 using a stretched finger and stretched hand illusion that increased perceived body size at the site of stimulation and away from the site of stimulation respectively. An additional illusion condition that gave participants the impression that the tip of their index finger was detached from the rest of the finger was also included to examine how observing body discontinuity would affect tactile perception. Participants completed the SSDT under the influence of three of multisensory illusions including 'stretched finger', 'stretched hand' and 'detached finger' as well as a veridical condition in which no illusion was applied. In line with the findings of Kennett et al. (2001) and de Vignemont et al. (2005), an increase in correct tactile reports was expected when the finger appeared to be stretched. If the increased tactile acuity reported in previous studies was due a general increase in the perceived size of the stimulated body part, a similar increase in correct tactile reports was expected during the stretched hand condition as well. Alternatively, no increase (or a reduction) in correct touch reports during the stretched hand condition would suggest that improved tactile detection is specific to the body site at which tactile vibrations are applied. Finally, in line with previous findings we expected the finger to be disembodied during the detached condition (Newport & Preston, 2010; Perez-Marcos, Sanchez-Vives, Slater, 2012; Tieri, Tidoi, Pavone & Aglioti, 2015) and given

that disembodiment of a limb has been found to result in reduced physiological responses and slower tactile processing (Moseley et al., 2008) it could perhaps be expected that tactile sensitivity maybe reduced when the finger appeared to be ‘detached’.

5.3 Experiment 1 Method

5.3.1 Participants

Thirty one right-handed (Oldfield, 1971) participants (13 male) aged 18 to 27 years (mean age=20.97; SD=1.96) were recruited. Written informed consent was obtained prior to participation and none of the participants reported any sensory deficits. All procedures were approved by the University of Nottingham Malaysia Campus Research Ethics Committee. Participants were compensated with 1 course credit (psychology students) or RM 8.

5.3.2 Apparatus and Material

a) Questionnaire measures

Trait Anxiety Inventory: The trait anxiety scale (STAI-T) from the State-Trait Anxiety Inventory (Spielberger, Gorssuch, Lushene, Vagg & Jacobs, 1983) was used to control for trait negative affect (Watson & Pennebaker, 1989) as this has been found to affect somatic sensation such that higher negative affect scores are associated with perceiving benign somatic sensations as being particularly disturbing/intense.

Somatosensory Amplification scale (SSAS; Barsky, Wyshak & Klerman, 1990) In light of evidence suggesting that somatic sensitivity and amplifying ambiguous sensory information is related to somatic somatosensation (Barsky,

Goodson, Lane, & Cleary, 1988) individual scores on this scale were included as covariates in the analyses to control for such effects.

As in the previous chapters, the acclimatisation questionnaire (Newport, Pearce & Preston, 2010) was used to measure sense of ownership towards the video image of the hand in its actual location prior to the illusions when seen through the mirror of the MIRAGE. Illusion strength and ownership questionnaires were used to assess the extent to which each illusion was incorporated into participants' body representation (adapted from Preston & Newport, 2012). These questionnaire items measured how strongly participants felt each multisensory illusion and participants' sense of ownership towards the distorted appearance of their finger/hand. In both questionnaires participants made verbal judgements on a 9 point numeric rating scale in which 9 indicated strong illusion strength/ownership and 1 indicated the low illusions strength/ownership.

b) MIRAGE system

The MIRAGE system was used to generate illusions (Newport, Preston, Pearce & Holton, 2009; Newport et al., 2010). Participants were presented with three multisensory illusions on their hand or index finger (see Figure 5.1); 'stretched finger', 'stretched hand' and 'detached finger'. During the stretched finger and stretched hand conditions (images and detailed description in chapter 3), the experimenter grasped and pulled participants' index finger/hand with slight pressure while the image of their finger/hand (seen through the device) was simultaneously seen to grow longer (Preston & Newport, 2011). During the detached finger condition the distal end of the index finger was grasped and pulled until it was stretched (increased in length) and then 'detached' from the rest of the finger. As in the previous illusions, participants watched the region corresponding to second knuckle

increase in length until it was no longer connected to the rest of the finger (- the stump; Newport & Preston, 2010). Finally, as a visual convincer, a pen was passed through the detached part of the finger and the stump.

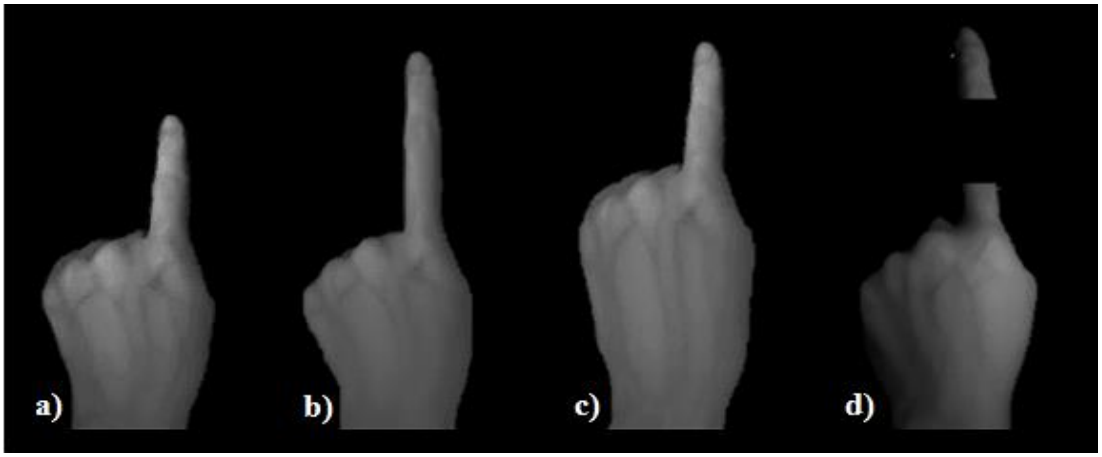


Figure 5.1: Multisensory illusions and veridical condition: (a) Veridical (b) Stretched finger (c) Stretched hand (d) Detached finger

c) SSDT stimulus array

The stimulus array of the SSDT consisted of a foam wedge onto which a tactor – consisting of a miniature electromagnetic solenoid stimulator (Dancer Design tactor; diameter 1.8 mm; see Appendix 4 for further information on tactor) and a light-emitting diode (LED) 4 mm in diameter were mounted. The participant's index finger, to which tactile pulses were delivered, was then attached to the tactor with double sided adhesive tape. 20ms tactile pulses were produced by sending amplified square wave sound files (100 Hz) to the tactor and were controlled by e-prime software (Psychology Software Tools Inc., Pittsburgh, PA, USA). The intensity of the stimuli was controlled by an amplifier (Dancer Design TactAmp). An LED attached next to the stimulus array flashed for 250ms and signalled the start of each trial prompting participants to look at their index finger. White noise was played via headphones throughout the experiment to prevent participants from hearing any experimentally informative sounds from the electromagnetic solenoid stimulator.

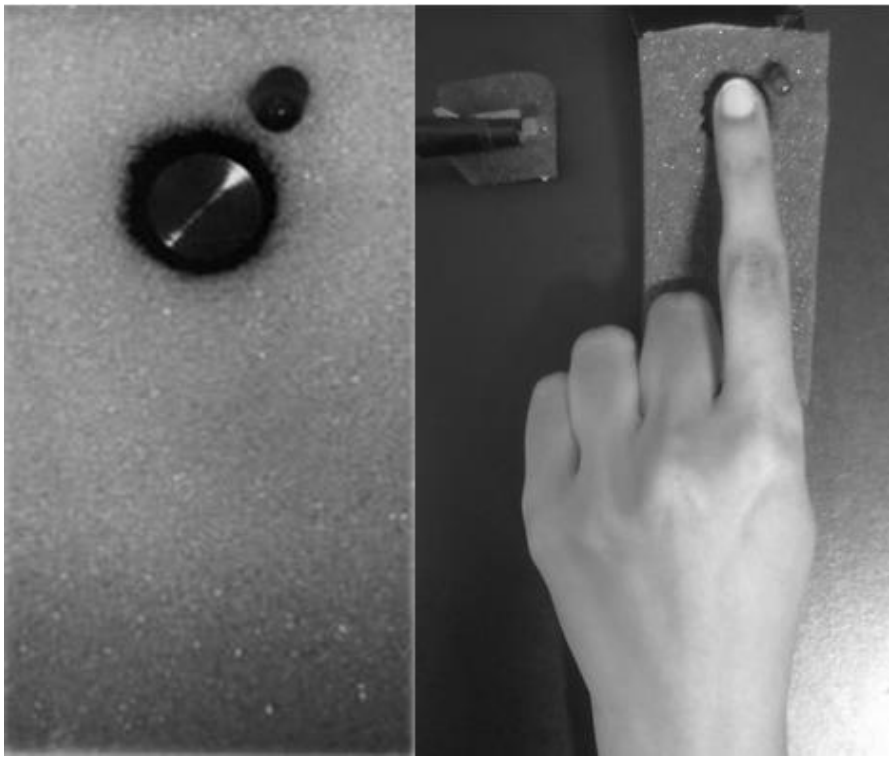


Figure 5.2: SSDT stimulus array

Thresholding procedure: A threshold was found for each participant using a staircase procedure (Cornsweet, 1962). Participants were presented with blocks of thirteen trials comprising of 10 tactile present and 3 tactile absent trials. The LED attached next to the stimulus array lit up for 250ms signalling the start of every trial. This was followed by a stimulus period of 1020ms. In vibration present trials, the tactile stimulus lasting 20ms was delivered to participants' index finger with a delay of 500ms before and after the stimulus. In vibration absent trials the LED start cue was followed by an empty period of 1020ms. At the end of each trial the experimenter asked the participant to report whether they did ("yes") or did not ("no") feel the vibration. The experimenter inputted participants' responses on a keyboard.

If the vibration was perceived on less than 40% of the stimulus present trials, intensity of the vibration was increased. If the vibration was perceived on more than

60% of the stimulus present trials, intensity was reduced, and this procedure was repeated until the stimulus intensity approached the participant's 50% threshold. This was considered to be the level necessary for the participant to correctly perceive the vibration on 40-60% of the trials, and participants had to score within this range on three consecutive blocks.

Experiment proper: The SSDT consisted of four blocks of 96 trials – each corresponding to one of the four experimental conditions (veridical, stretched finger, stretched hand and detached finger). In each block, four different trial types (vibration only, vibration plus light, light only and catch-no stimulus) were presented 24 times in a random order. The vibration was presented at the intensity previously determined during the thresholding procedure. Touch only and catch trials were identical to those presented during thresholding trials. In trials with a light, the LED (in the stimulus array) flashed for 20ms either alone (light only trials) or together with the vibration (light and touch trials). Participants were given no information about the purpose of light and were only asked to indicate whether or not they felt a vibration at the end of each trial using "yes" and "no" responses (see Figure 5.2).

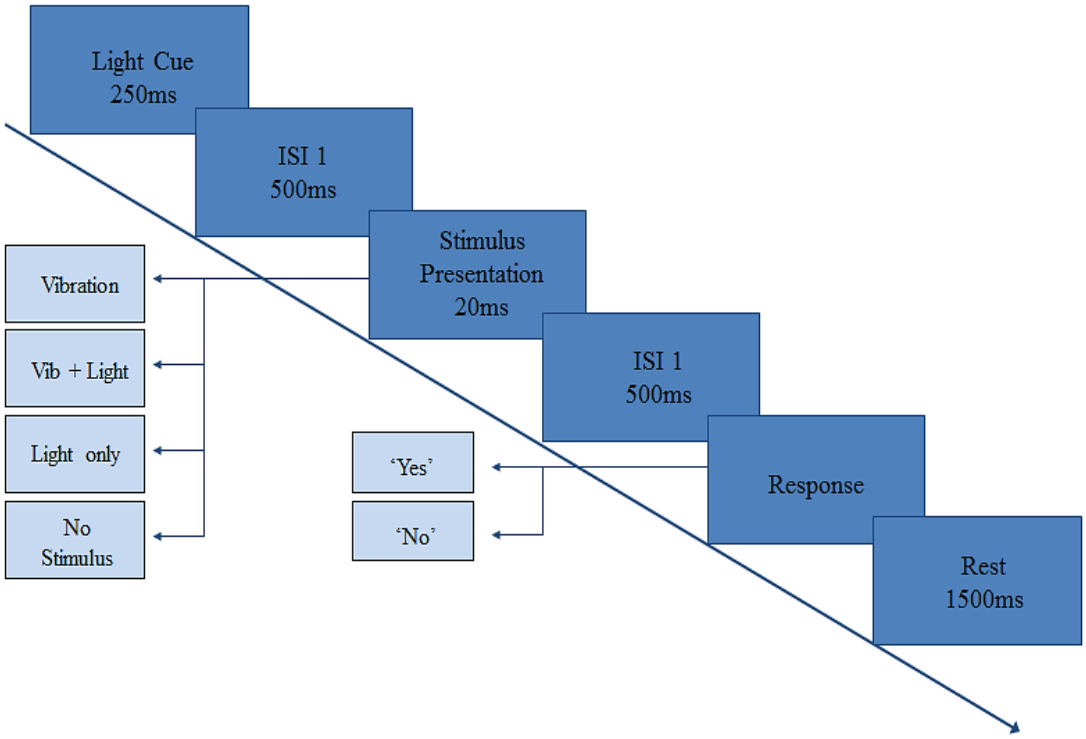


Figure 5.3: SSDT paradigm

5.3.3 Design and Procedure

This study used a 4 X 2 X 2 repeated measures design in which condition (veridical, stretched finger, stretched hand, detached finger), light (present, absent) and vibration (present, absent) were within-participant variables and the participant's responses "yes" and "no" were the dependent variables.

Participants initially received both written and verbal instructions about the task, after which they were seated in front of the MIRAGE mediated reality device. They were then given a brief period of acclimatisation (approximately 30 seconds) during which time they viewed their un-manipulated hand moving freely in its actual location. Following this, the acclimatisation questionnaire was administered. Next, the participants' left index finger was placed on the SSDT stimulus array and his/her individual tactile threshold was found using the staircase procedure described above. This was followed by the experiment proper.

During the experiment proper, an illusion or baseline condition was first conducted after which participants responded to illusion strength and hand ownership questionnaires corresponding to a particular condition prior to completing the SSDT. Each condition was conducted in a counter balanced order. At the end of each block, the participant's finger/hand was brought back to its original length and a break of 3 minutes was given before the next condition began. Participants were still given a break during the veridical condition. All participants were also instructed to keep their hand still during the course of the experiment, and received no feedback.

5.4 Experiment 1 Results

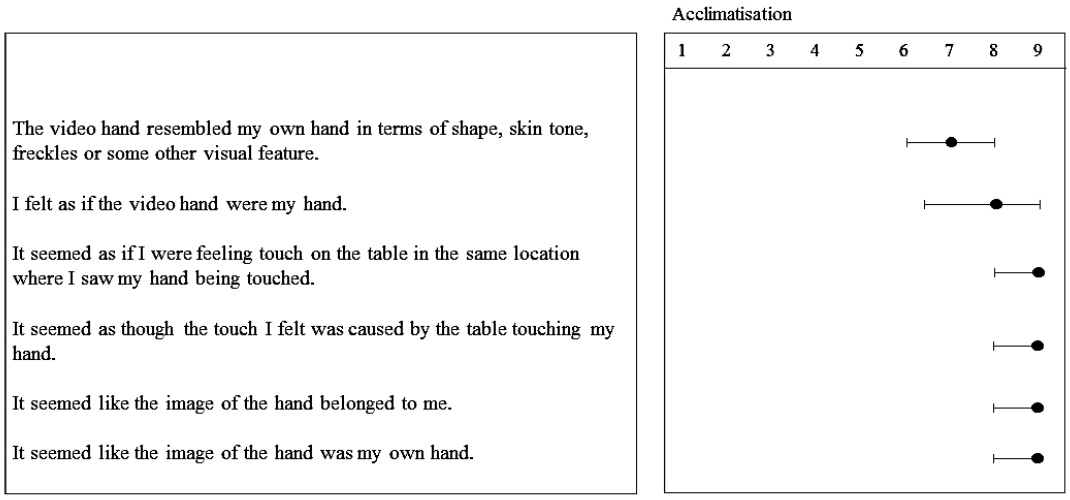
5.4.1 Questionnaire responses

All questionnaire ratings were significantly negatively skewed (Shapiro Wilk statistic showed that $p<.05$) and remained so following transformation, consequently non-parametric analyses were used.

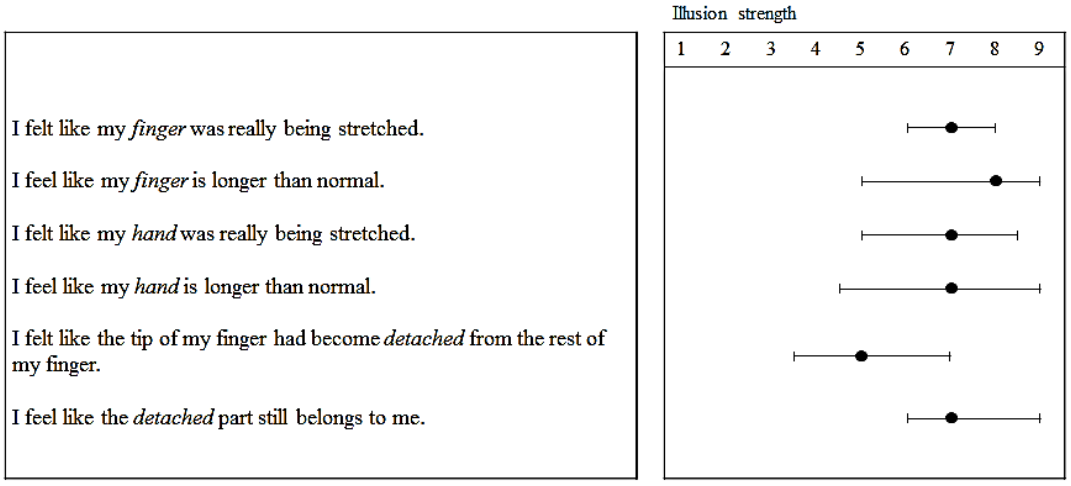
Acclimatisation questionnaire: Responses to this questionnaire showed a strong sense of ownership towards the video image of the hands (see Figure 5.3a). Participants strongly agreed with statements such as *'It seemed like the image of the hand belonged to me'* (Median= 9) and *'It seemed like the image of the hand was my own'* (Median= 9).

Illusion strength and hand ownership questionnaires: Illusion strength and hand ownership responses for each condition were separately examined. Ratings to ownership statements indicated that participants strongly agreed that the video image of the hand belonged to them in all conditions whereas illusion strength ratings indicated that participants strongly felt their finger and hand being stretched, but felt the detached finger condition to a lesser extent (see Figure 5.3b-c).

a) Acclimatization questionnaire



b) Illusion strength statements



c) Ownership statements

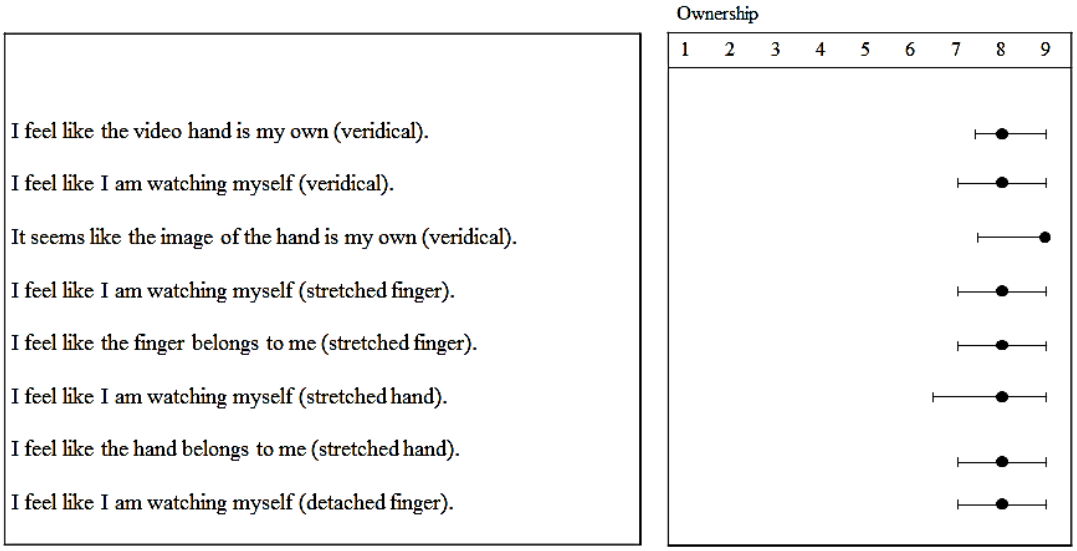


Figure 5.4a-c: Medians and inter-quartile ranges for questionnaire ratings: (a) Acclimatisation (b) Illusion strength statements (c) Ownership statements

Illusion strength ratings and hand ownership across the three illusion conditions were then separately compared. Ratings to the statements '*I felt like my finger/hand was really being stretched'* and *'I feel like my finger/hand is longer than normal'* were separately averaged for the stretched finger and hand conditions to obtain mean scores of illusion strength. Ratings to the statement *'I feel like the detached part still belongs to me'* was reverse scored and averaged with ratings to the statement *'I felt like the tip of my finger had become detached from the rest of my finger'* to obtain mean illusion strength ratings for the detached condition. A Freidman's ANOVA conducted on mean illusion strength ratings revealed significant differences between the three illusion conditions (χ^2 (2, N=31) = 29.60, p<.001). Wilcoxon signed-ranks tests (with a Bonferroni corrected significance level of .016) indicated higher illusion strength ratings when the finger felt to be stretched (Median= 7) compared to when it felt to be detached (Median= 4.5; Z= -4.23, p<001, r=.76) indicating that participants did not strongly feel the tip of their finger being detached.

Illusion strength was also higher when the hand was stretched (Median= 7) compared to when the finger was detached (Median= 4.5; Z= -3.93, p<001, r=.71). No difference in mean illusion strength was seen between the stretched finger (Median=7) and stretched hand (Median=7) conditions (Z= -.88, p=.38). The statement *'I feel like I am watching myself'* was common across all four conditions (veridical and illusion) and indicated sense of ownership towards (un)manipulated representations of the hand and finger. Ratings to this statement were therefore compared across all four conditions. A Freidman's ANOVA revealed no significant difference between the three multisensory illusions or the baseline condition (χ^2 (3, N=31) = 4.54, p=.21).

5.4.2 SSDT parameters

Participants' "yes" and "no" responses were categorised as hits (touch present trials with a correct 'yes' response), misses (touch present trials with an incorrect 'no' response), false-alarms (touch absent trials with an incorrect 'yes' response) and correct rejections (touch absent trials with a correct 'no' response). These were then used to calculate hit rates [hits+0.5/(hits+misses+1)], false-alarm rates [false-alarms+0.5(false-alarms +correct rejections +1)], and the signal detection theory test statistics *d'* [z(hit rate)-z(false-alarm rate)] and *c* [-.5 x z(hit rate) + z(false-alarm rate)] (MacMillan & Creelman 1991), with the log linear correction (Snodgrass & Corwin 1988), providing estimates of the participants' perceptual sensitivity (*d'*) and response criterion (*c*; the tendency to report feeling the vibration regardless of whether or not one was present) in the presence and absence of light. Descriptive statistics for hit rates, false-alarm rates, sensitivity and response criterion across all conditions are summarised in Table 5.1 below.

Table 5.1: Means (and standard deviations) for hit rates, false-alarm rates and signal detection theory test statistics for all conditions in the presence and absence of light

Condition	Hits (%)	False-alarms (%)	*d'*	*c*
Veridical condition				
Light	54.39 (21.35)	41.24 (20.55)	1.11 (1.09)	0.44 (0.38)
No light	58.39 (18.89)	40.22 (23.71)	1.29 (1.24)	0.38 (0.44)
Stretched finger				
Light	65.61 (22.21)	42.95 (21.54)	1.40 (1.10)	0.23 (0.52)
No light	57.35 (21.47)	37.11 (19.93)	1.37 (0.88)	0.45 (0.51)
Stretched hand				
Light	63.68 (20.36)	38.14 (23.87)	1.51 (1.06)	0.38 (0.54)
No light	55.03 (23.23)	33.97 (20.02)	1.46 (1.20)	0.53 (0.42)
Detached finger				
Light	54.77 (23.13)	39.44 (21.90)	1.20 (1.07)	0.46 (0.51)
No light	51.42 (25.89)	35.70 (13.94)	1.22 (1.00)	0.56 (0.42)

A series of 2 x 4 repeated measures ANOVAs with light (2; present and absent) and condition (4; *i.e.*, veridical, stretched finger, stretched hand and detached finger) as within subject factors were conducted on hit rates, false-alarm rates, tactile sensitivity (*d'*) and response criterion (*c*).

Hit rates

Hit rates were significantly higher in the presence of light ($F_{(1,30)}$= 8.33, p=.007, η_p^2= .22). No main effect of condition was seen ($F_{(3,90)}$= 1.33, p=.27) however the interaction between light and condition was significant ($F_{(3,90)}$= 4.67, p=.004, η_p^2=.14). Post hoc *t*-tests revealed significantly higher hit rates in the presence of light during the stretched finger condition ($t_{(30)}$=2.94, p=.006, d=.38). Hit rates were also significantly greater in the presence of light, during the stretched hand condition ($t_{(30)}$=3.10, p=.004, d=.40). The findings remained the same when controlled for STAI-T and SSAS.

False-alarm rates

False-alarm rates were not normally distributed, a square root transformation was therefore applied to normalise the data. A strong trend towards a main effect of light, with more false-alarms reported in the presence of light overall ($F_{(1,30)}$= 4.11, p=.052, η_p^2=.12). No main of condition ($F_{(2.14,64.27)}$=1.24, p=.30) or interaction between light and condition was seen ($F_{(2.25,67.48)}$=.66, p=.58). When STAI-T and SSAS were included as covariates the strong trend for the main effect of light improved to a significant effect ($F_{(1,28)}$= 4.64, p=.040, η_p^2=.14) with more false-alarms reported in light present trials.

Tactile sensitivity (d')

No main effect of light ($F_{(1,30)}$= .66, p=.20) or condition ($F_{(1.99,59.75)}$= 1.09, p=.34) was observed for sensitivity. These two factors were also not found interact ($F_{(3,90)}$= .65, p=.59). Results remained the same when STAI-T and SSAS were included as covariates.

Response criterion (c)

Response criterions were significantly lower in the presence of light ($F_{(1,30)}$= 5.34, p=.028, η_p^2= .15) indicating that participants were more likely to report feeling the vibration regardless of whether or not one was present. No main effect of condition was seen ($F_{(3,90)}$= 1.84, p=.15), however, the interaction between light and condition was found to be significant ($F_{(3,90)}$= 2.81, p=.044, η_p^2= .086). Post hoc *t*-tests showed response criterion to be significantly lower in the presence of light during the stretched finger condition ($t_{(30)}$=3.17, p=.004, d=.43). A strong trend towards lower response criterions in the presence of the light was seen during the

stretched hand condition ($t_{(30)}$=1.99, p=.055, d=.32). These findings remained the same when STAI-T and SSAS were included as covariates.

5.5 Experiment 1 Discussion

The aim of Experiment 1 was to investigate whether perceived enlargement of body size at the site of stimulation and away from the site of stimulation had different effects on near threshold tactile perception. In line with previous studies (Kennett et al., 2001; de Vignemont et al., 2005), increasing perceived body size at the site of stimulation (during the stretched finger condition) was found to enhance correct tactile perception (hits) in light present trials. Interestingly, an increase in perceived hand size (away from the site of stimulation) also improved correct tactile perception in the presence of the light. The absence of any significant increase in incorrect touch reports (false-alarms) during the two conditions suggest that the observed differences in response criterion (during the stretched finger and hand conditions) could be largely attributed to the increase in hits rather than to a general tendency of responding positively across all trials. These findings thus extend previous literature (Kennett et al., 2001) by demonstrating that an increase in body size perception both at the site of stimulation and away from the site of stimulation may bias tactile perception by enhancing correct tactile judgements.

Importantly, both illusion strength and ownership ratings were found to be high and no differences in ownership were found between the two conditions suggesting that ownership was not lost as a result of the multisensory distortions. Unexpectedly however, participants reported low illusion strength scores during the detached finger condition and retained ownership over the finger. Moreover, no overall difference in tactile detection during the detached condition was seen. It is

unclear why this was the case, however such a finding could perhaps be a result of carryover effects from the previous conditions and the absence of an appropriate comparison baseline.

The task irrelevant light significantly increased reports of feeling the vibration regardless of whether or not one was present; leading to increases in both hit rates and false-alarm rates. The findings replicate previous findings (Johnson, Burton & Ro, 2006; Lloyd et al., 2008; McKenzie, Poliakoff, Brown et al., 2010; Mirams et al., 2010), and suggest that when tactile information is unreliable or uncertain, participants rely on incoming visual information in their decisions relating to the tactile event. The effect of light on false touch reports was only apparent when controlling for the covariates SSAS and STAI-T. This provides evidence for an overlap between somatosensation and subjective judgements of trait anxiety and tendencies of experiencing ambiguous sensory information as being particularly disturbing.

In summary, Experiment 1 has extended previous findings (Kennett et al., 2001; de Vignemont et al., 2005) by showing that an increase in perceived body size both at the site of stimulation and away from the site of stimulation have similar behavioural outcomes in terms of near threshold tactile perception, thus suggesting that improved tactile perception maybe a result of a general increase in perceived size of a stimulated body part. Such a finding may perhaps be a result of these somatic distortions activating the salience network (Ehrsson, Wiech, Weiskopf, Dolan & Passingham, 2007) including the insula, anterior cingulate gyrus and amygdala (Menon, 2015) which may have in turn resulted in increased awareness of somatic sensations (Parvizi, Rangarajan, Shirer, Desai & Greicius, 2013). Alternatively, similar behavioural outcomes in terms of tactile perception may also suggest general

attention or novelty effects. Viewing stretched representations of the hand or finger is unusual in daily life, therefore, the manipulated representations may have drawn more attention to the hand and finger in general, thus improving tactile detection. In conclusion, while in previous studies the precise mechanisms underlying improved tactile perception was unclear; these findings demonstrated that such an effect is driven by liberal response criterions, rather than an increase in tactile sensitivity.

5.6 Experiment 2

Unfortunately, Experiment 1 provided no baseline estimates of tactile perception, as the veridical condition was intermixed with the illusion conditions. Therefore, in Experiment 2 the veridical condition was used as a baseline reference by which performance in other multisensory illusion conditions could be compared against (Kennett et al., 2001). All predictions could therefore be tested *a-priori* using direct comparisons between the veridical-baseline condition and the multisensory illusion conditions; however, Bonferroni corrected pairewise comparisons will still be reported following significant main effects with the aim of painting a clearer picture of the processes underlying altered response patterns. Furthermore, while Experiment 1 provided evidence suggesting that somatic manipulations of the body modulates tactile processing by improving tactile detection following an increase in perceived size of a stimulated body part, regardless of the site of stimulation; it remains a question whether the observed increase in tactile perception was due to a perceived increase in size of the stimulated body part or merely a change in perceived body size. Therefore, Experiment 2 also included an additional illusion that gave participants the impression that their hand was shrunken. If the inclusion of this illusion led to bidirectional modulatory effects on touch, then this would rule out explanations based

merely on a change in perceived body size. More specifically, if the observed increase in correct tactile reports in Experiment 1 was due to an increase in perceived size of the stimulated body part, one of two outcomes were predicted; the shrunken hand condition would be expected to result in a significant reduction in tactile perception or no difference in tactile perception compared to the baseline condition. In line with Experiment 1, significantly more correct touch reports were predicted during stretched hand and stretched finger conditions. The detached condition was again included to examine how observing body discontinuity would affect tactile perception. In line with previous studies (Newport & Preston, 2010; Perez-Marcos et al., 2012; Tieri et al., 2015) the detached appearance was expected to lead to reduced tactile sensitivity compared to baseline.

5.7 Experiment 2 Method

5.7.1 Participants

Thirty six right handed participants (12 male) aged 18 to 26 years (mean age=19.53, SD= 1.31) from the University of Nottingham Malaysia campus were recruited. None of the participants reported any sensory deficits and written informed consent was obtained prior to participation. All participants were compensated with 1 course credit (psychology students) or RM8.

5.7.2 Apparatus and material

a) Questionnaire measures

As in Experiment 1, the trait anxiety index from the state-trait anxiety inventory and somatosensory amplification scale were used to control for negative affect and tendencies of amplifying ambiguous sensory information respectively.

The acclimatisation and illusion strength and ownership questionnaires were also used to assess sense of ownership towards the video images of the hand as well as to measure the extent to which each illusion was incorporated into participants' body representation. In Experiment 2, an additional illusion strength and ownership questionnaire assessing how strongly participants felt the shrunken hand illusion ('I felt like my hand was really being shrunken') and participants' sense of ownership towards this distorted appearance of their hand ('I feel like I am watching myself') was included.

b) MIRAGE system

The stretched finger, stretched hand and detached finger conditions were conducted following the same procedure as that described in Experiment 1. During the shrunken hand illusion, the experimenter gently 'pushed' participants' hand while they simultaneously watched their hand shrink (see Figure 5.4a-e).

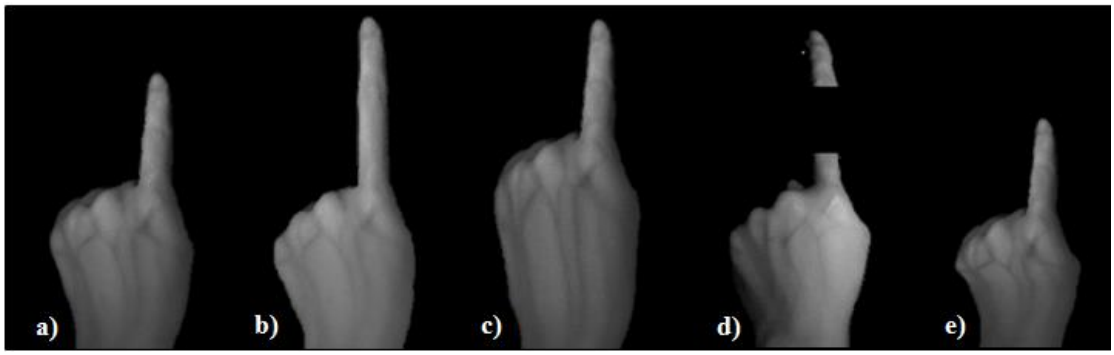


***Figure 5.5a-e**:* Multisensory illusions and veridical baseline condition: (a) Veridical baseline (b) Stretched finger (c) Stretched hand (d) Detached finger (e) Shrunken hand

c) Somatic signal detection task

The experimental setup was identical to that of Experiment 1. As in Experiment 1, participants' individual tactile threshold was found after which experiment proper was conducted. Experiment proper consisted of five blocks of 80

trials – each corresponding to one of the five experimental conditions (veridical-baseline, stretched finger, stretched hand, shrunken hand and detached finger). As stated in Experiment 1, four different trial types (vibration only, vibration plus light, light only and catch-no stimulus) were presented 20 times in a randomised order in each block and participants indicated whether or not they felt the vibration using "yes" and "no" responses.

5.7.3 Design and Procedure

A 5 X 2 X 2 repeated measures design was employed, in which condition (veridical baseline, stretched finger, stretched hand, shrunken hand and detached finger), light (present, absent) and tactile vibration (present, absent) were within-participant variables and participants' "yes" and "no" responses were the dependent variable. The procedure was identical to that of Experiment 1, however, during the experiment proper participants first responded to statements assessing their sense of ownership towards the video image of their hand during the veridical-baseline condition, after which they completed the first block of the SSDT. The veridical condition was used as a baseline reference by which performance in other illusions was compared against (Kennett et al., 2001) and was conducted first for all participants to ensure that it was not contaminated by any carryover effects from the four multisensory illusions. Following the veridical-baseline condition participants were subjected to one of the four multisensory illusions in a counter-balanced order.

5.8 Experiment 2 Results

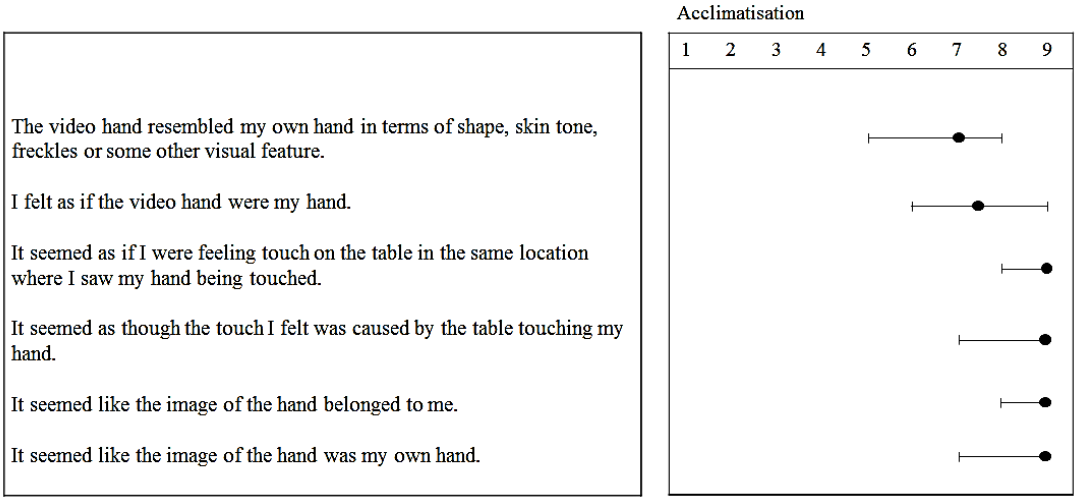
5.8.1 Questionnaire responses

All questionnaire ratings remained not normally distributed following attempts to transform the data (Shapiro Wilk statistic showed that $p<.05$) consequently, non-parametric analyses were conducted.

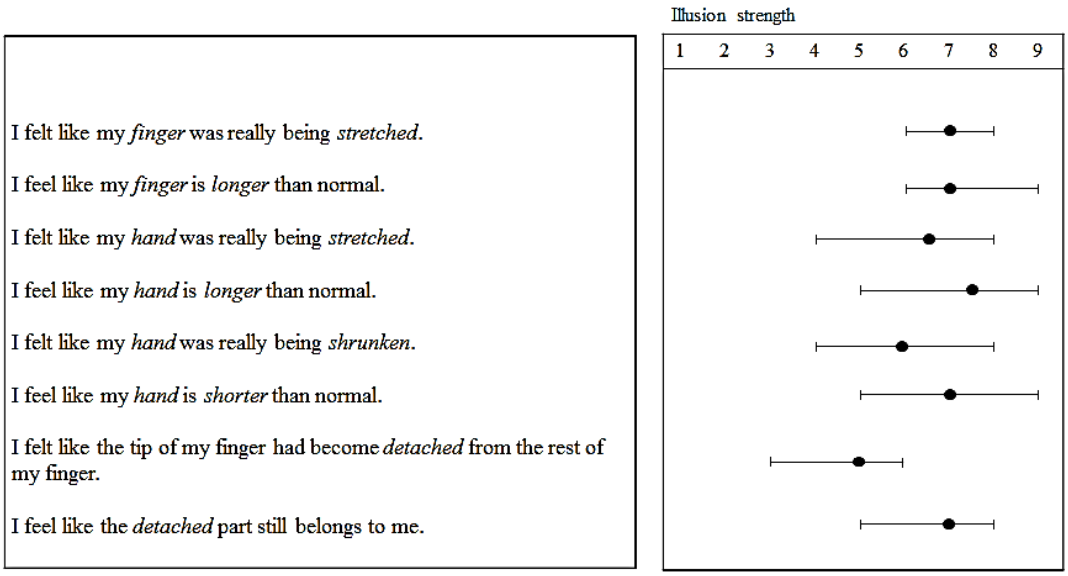
Acclimatisation questionnaire: Responses to this questionnaire showed a strong sense of ownership towards the video image of the hands (see Figure 5.5a). Participants strongly agreed with statements such as *'It seemed like the image of the hand was my own'* (Median= 9) and *'It seemed like the image of the hand belonged to me'* (Median= 9).

Illusion strength and hand ownership questionnaires: Illusion strength and hand ownership responses for each condition were separately examined. In line with Experiment 1 ownership ratings indicated that participants agreed that the video image of the hand belonged to them in all conditions whereas illusion strength ratings indicated that participants felt the detached finger condition the least (see Figure 5.5b-c).

a) Acclimatisation questionnaire



b) Illusion strength statements



c) Ownership statements

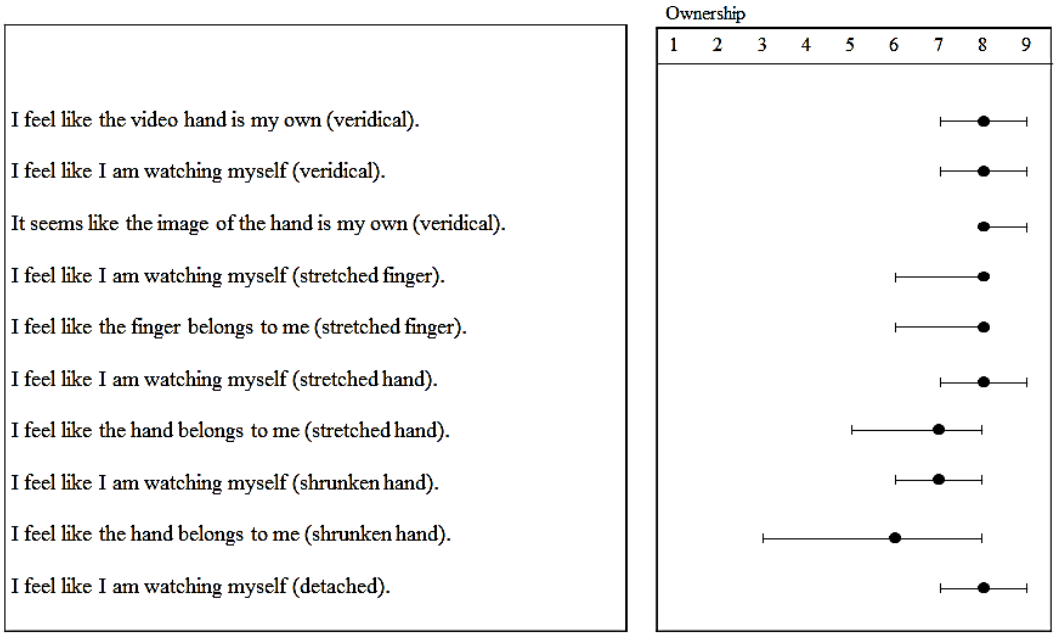


Figure 5.6a-c: Medians and inter-quartile ranges for questionnaire ratings: (a) Acclimatisation (b) Illusion strength statements (c) Ownership statements

Illusion strength and hand ownership ratings across the three conditions were then analysed separately. As in Experiment 1, mean illusion strength ratings were calculated separately for the stretched finger, stretched hand and shrunken hand conditions by averaging ratings to the statements *'I felt like my finger/hand was really being stretched/shrunken'* and *'I feel like my finger/hand is longer/shorter than normal'*. Ratings to the statement *'I feel like the detached part still belongs to me'* was again reverse scored and averaged with ratings to the statement *'I felt like the tip of my finger had become detached from the rest of my finger'* to obtain mean illusion strength ratings for the detached condition. A Freidman's ANOVA conducted on mean illusion strength ratings across the four multisensory illusions revealed significant differences between the conditions (χ^2 (3 N=36) = 51.56, p<.001). Wilcoxon signed-ranks tests (with a Bonferroni corrected significance level of .0083) indicated higher illusion strength ratings during the stretched finger (Median= 7) compared to detached finger condition (Median= 4.5; Z= 4.44, p<001, r=.74). Illusion strength was also higher during the stretched hand (Median= 6.5) compared to the detached finger condition (Median= 4.5; Z= 4.19, p<001, r=.70) as well as during the shrunken hand (Median= 6.5) compared to the detached finger condition (Median= 4.5; Z= 4.35, p<001, r=.73). None of the other differences were found to be significant (all p>.0083). The statement '*I feel like I am watching myself'* was common across all five conditions (baseline and illusion) and indicated sense of ownership towards the (un)manipulated representations of the hand and finger. Ratings to this statement were therefore compared across all conditions. Interestingly, a Freidman's ANOVA revealed significant differences in ownership between the conditions (χ^2 (4, N=36) = 20.20, p<.001). Wilcoxon signed-ranks tests (with a Bonferroni corrected significance level of .005) indicated lower illusion strength

ratings during the shrunken hand condition (Median= 7) compared to the veridical baseline condition (Median= 8; Z= -3.25, p=.001, r=.54). Ownership was also lower during the shrunken hand condition (Median=7) compared to the stretched hand condition (Median= 8; Z= -2.86, p=.004, r=.48) (Median =8). A significant difference between the detached finger (Median=8) and shrunken hand condition (Median=7) was also seen, with ownership again found to be lower for the shrunken hand condition (Z= -2.79, p=.005, r=.47). None of the other differences were found to be significant (all p>.005).

5.8.2 SSDT parameters

As in Experiment 1, hit rates and false-alarm rates were used to calculate signal detection theory test statistics; sensitivity (d') and response criterion (c). Descriptive statistics for hit rates, false-alarm rates, sensitivity and response criterion across all conditions are summarised in Table 5.2 below.

Table 5.2: Means (and standard deviations) for hit rates, false-alarm rates and signal detection theory test statistics for all conditions in the presence and absence of light.

Condition	Hits (%)	False-alarms (%)	*d'*	*c*
Veridical baseline				
Light	49.21 (14.33)	44.75 (19.73)	0.86 (0.85)	0.45 (0.37)
No light	42.20 (16.54)	38.65 (16.94)	0.86 (0.73)	0.65 (0.39)
Stretched finger				
Light	59.92 (17.46)	46.61 (20.78)	1.10 (0.93)	0.27 (0.43)
No light	51.46 (22.24)	39.12 (20.97)	1.14 (1.02)	0.51 (0.53)
Stretched hand				
Light	64.02 (16.88)	46.16 (20.18)	1.22 (0.93)	0.21 (0.41)
No light	56.08 (21.19)	39.34 (20.54)	1.27 (1.09)	0.29 (0.37)
Shrunken hand				
Light	64.02 (17.15)	41.38 (19.71)	1.39 (0.96)	0.29 (0.37)
No light	57.54 (17.48)	35.09 (17.27)	1.43 (0.87)	0.50 (0.37)
Detached finger				
Light	46.69 (17.48)	38.04 (18.30)	1.02 (0.88)	0.60 (0.36)
No light	38.89 (20.20)	37.83 (18.46)	0.79 (0.89)	0.72 (0.44)

A series of 2 X 5 repeated measures ANOVAs with light (2; present and absent) and condition (5; *i.e.*, veridical-baseline, stretched finger, stretched hand, shrunken hand and detached finger) as within subject factors were conducted on hit rates, false-alarm rates, tactile sensitivity (*d'*) and response criterion (*c*).

Hit rates

Hit rates were significantly higher in the presence of light ($F_{(1,35)}$= 19.96, p<.001, η_p^2= .36). A significant main effect of illusion condition was also seen ($F_{(4,140)}$= 12.67, p<.001, η_p^2=.27). Planned comparisons revealed significantly higher hit rates in the stretched finger condition compared to the veridical baseline condition ($F_{(1,35)}$= 10.14, p=.003, η_p^2=.23). Hit rates were also significantly higher in the stretched hand condition compared to the baseline condition ($F_{(1,35)}$= 22.72, p<.001,

η_p^2=.39) as well as during the shrunken hand condition compared to the baseline condition ($F_{(1,35)}$= 23.04, p<.001, η_p^2=.40). No difference was seen between the detached finger condition and veridical baseline condition ($F_{(1,35)}$= 1.15, p=.29). Pairwise comparisons revealed hit rates to be significantly higher during stretched finger compared to the detached finger (mean difference =.13, p=.014), the stretched hand compared to the detached finger (mean difference =.17, p<.001) and also during the shrunken hand compared to the detached finger condition (mean difference =.18, p<.001). No differences were however seen between the stretched finger, stretched hand and shrunken hand conditions (all p>.05). Light and condition were not found to interact ($F_{(4,140)}$= .11, p=.98). The findings remained the same when controlled for STAI-T and SSAS.

False-alarm rates

False-alarm rates were not normally distributed, a square root transformation was therefore applied to normalise the data. In the presence of the light false-alarm rates were found to be significantly higher ($F(_{1,35)}$= 14.59, p=.001, η_p^2=.05). No main effect of condition was seen ($F_{(4,140)}$= 2.13, p=.08, η_p^2=.297). The interaction between light and condition was also not significant ($F(_{4,140)}$= 1.89, p=.12, η_p^2=.051). These findings remained the same when the STAI-T and SSAS were included as covariates.

Tactile sensitivity (d')

A main effect of illusion condition was found ($F_{(4,140)}$= 5.79, p<.001, η_p^2=.14). Planned comparisons indicated a significantly greater tactile sensitivity during the stretched hand condition compared to the veridical baseline condition ($F_{(1,35)}$= 9.84, p=.003, η_p^2=.22). Tactile sensitivity was also significantly higher during the shrunken hand condition compared to the veridical baseline condition ($F_{(1,35)}$= 15.52, p<.001,

η_p^2=.31). A trend towards greater sensitivity during the stretched finger condition compared to the veridical baseline condition was seen ($F_{(1,35)}$= 3.54, p=.07, η_p^2=.09). Pairwise comparisons revealed no differences in tactile sensitivity between the stretched finger, stretched hand and shrunken hand conditions (p>.05), however, tactile sensitivity during the shrunken hand condition was significantly greater than the detached condition (mean difference = .51, p=.010). No main effect of light ($F_{(1,35)}$= .12, p=.73), and no interaction was observed ($F_{(4,140)}$= 1.42, p=.23, η_p^2=.039). No difference was found when the STAI-T and SSAS were included as covariates.

Response criterion (c)

Response criterion was significantly lower in the presence of light, suggesting that participants were more likely to report feeling a vibration when the light was present ($F_{(1,35)}$= 22.81, p<.001, η_p^2=.40) – regardless of whether or not a vibration had been present. A significant main effect of illusion condition was also seen ($F_{(3.24,113.24)}$= 10.23, p<.001, η_p^2=.23). Planned comparisons indicated that participants were more likely to report feeling the vibration during the stretched finger condition compared to the veridical baseline condition ($F_{(1,35)}$= 5.79, p=.022, η_p^2=.14). Participants were also significantly more likely to report feeling the vibration during the stretched hand condition compared to the veridical baseline conditions ($F_{(1,35)}$= 14.78, p<.001, η_p^2=.30) as well as during the shrunken hand condition compared to the veridical-baseline condition ($F_{(1,35)}$= 10.64, p=.002, η_p^2=.23) however less inclined to report feeling the vibration during the detached finger condition compared to the veridical baseline condition ($F_{(1,35)}$= 5.12, p=.029, η_p^2=.13). Pairwise comparisons revealed no significant differences between the stretched finger, stretched hand and shrunken hand conditions (all p>.05), however, response criterions were more stringent during the detached condition compared to the stretched finger (mean

difference =.27, p=.007), stretched hand (mean difference =.34, p<.001) as well as the shrunken hand (mean difference =.26, p<.001) conditions. Light and illusion condition were not found to interact ($F_{(4,140)}$= .89, p=.47). These results remained the same when SSAS and STAI-T scores were included as covariates.

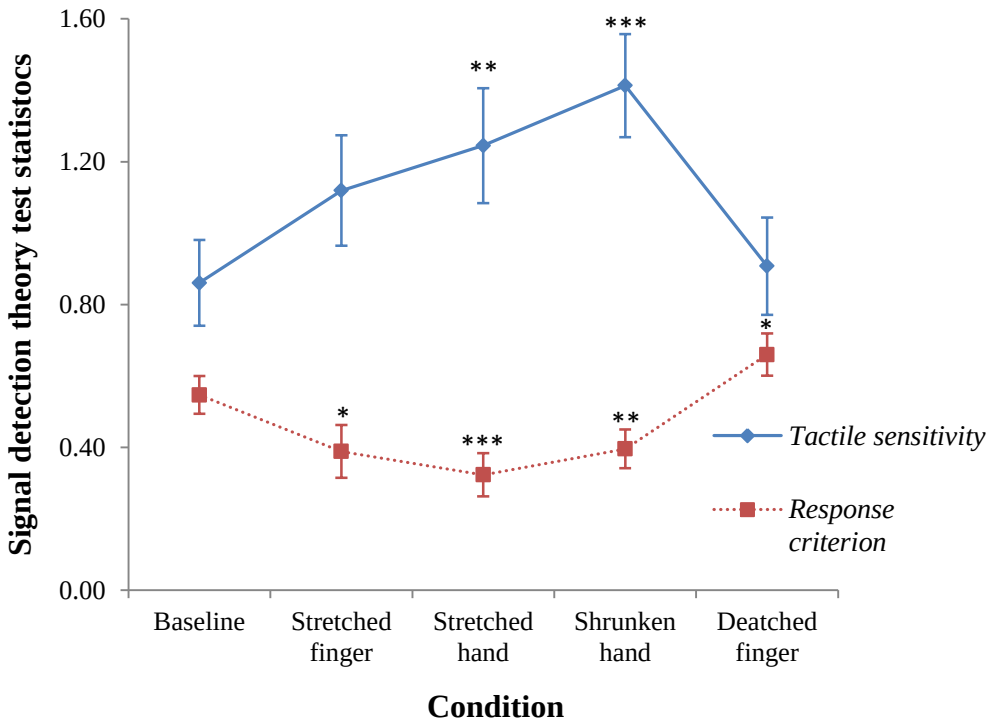


Figure 5.7: Mean tactile sensitivity (d') and response criterion (c) for each condition. Error bars show standard error of the mean. Asterisks indicate the significant difference between the veridical baseline condition and illusion conditions (*p<.05, **$p \leq .01$, ***$p \leq .001$)

5.9 Experiment 2 Discussion

This second study investigated whether changes in near threshold tactile detection was a result of an increase in perceived size of the stimulated body part or merely a result of altering the visual appearance of the body-part. Improved hit rates were observed following all three size altering illusions. While at first glance, this may suggest a general effect as a result of the altered body sizes, different underlying mechanism seemed to drive these behavioural outcomes. Improved tactile detection

during the stretched finger condition was found to be driven by liberal response criterions. The absence of any significant change in false-alarm rates during this condition suggests that the improved hit rates could be attributed to the change in response criterion. In contrast, the improved hit rates during the stretched and shrunken hand conditions were found to be driven by changes in response bias and sensitivity. Both conditions revealed better tactile sensitivity, demonstrating an improved ability to discern between tactile present and absent trials. Response criterions were also more liberal during these conditions; however this change was not associated with increased false-alarm rates thus suggesting that the change in response criterion could be attributed to the increased hit rates during the stretched and shrunken hand conditions. While these findings may suggest that different processes may operate in altering tactile perception following illusory manipulations of body size at the site of stimulation and away from the site of stimulation, pairwise comparisons revealed no significant differences in tactile sensitivity or response criterion across the size altering illusion conditions. This suggests that the underlying mechanisms may not be straightforward and that there might be an overlap in the effects exerted by the size altering illusion, the reasons for which are explored in the general discussion. Finally, while Experiment 1 only reported improved tactile detection in the presence of the task irrelevant light during the finger stretched and hand stretched conditions, Experiment 2 found overall improvements in tactile perception during the stretched finger condition while the stretched hand was found to improve tactile detection as a result of the both a liberal response criterion as well as increased tactile sensitivity. This discrepancy between Experiments 1 and 2 could have been a result of the absence of an appropriate baseline in Experiment 1, as the veridical condition was intermixed with the rest of the illusions and may have

therefore been influenced by the illusions. In contrast, the veridical condition was used as a reference by which other illusions were compared against and therefore conducted first in Experiment 2 (and 3) and may have therefore provided more accurate comparisons across the conditions.

No differences in terms of illusion strength were seen across these three conditions, however, differences were found in terms of sense of ownership over the manipulated representations of the hand. Results indicated reduced ownership over the shrunken hand compared to the veridical baseline condition, stretched finger and detached finger conditions. This reduced ownership could perhaps be a result of the shrunken hand appearing to be more unnatural to participants, as it does not complement the direction of growth. Importantly however, it should be noted that ownership was not lost during this condition. Ownership ratings were still above the mid-value 5. Despite the reduced ownership over the shrunken hand condition, tactile sensitivity and correct tactile reports were found to be significantly higher during this condition. The difference between the questionnaire ratings and performance on the SSDT could therefore, be a result of the subjective nature of the illusion strength and ownership questionnaires employed in the current study, therefore future studies should incorporate more objective measures when assessing sense of ownership over manipulated representations of the body such as skin conductance responses (SCR) and temperature changes.

During the detached condition response criterion was found to be significantly more stringent compared to all conditions, suggesting that participants were less likely to report feeling the vibration during this condition. Contrary to what was expected, illusion strength ratings again indicated that participants felt this illusion the least whilst ownership ratings were still high. Such findings could perhaps be a result of

different techniques used to measure ownership (Newport & Preston, 2010; Perez-Marcos et al., 2011) or due to differences in the way body discontinuity was examined in previous studies. (Perez-Marcos et al., 2011; Tieri et al., 2015; more details in general discussion)

The task irrelevant light again significantly increased reports of feeling the vibration regardless of whether or not one was present; leading to increases in both hit rates and false-alarm rates. This result has been previously reported in bimodal studies involving visual and tactile stimuli (Johnson et al., 2006; Lloyd et al., 2008), and suggest that ambiguous tactile events are affected by task irrelevant concurrent visual stimuli (Spence, Pavani & Driver, 2004).

In summary, Experiment 2 extended findings of Experiment 1 as well as previous studies (Kennett et al., 2001; de Vignemont et al., 2005) by demonstrating that manipulating the perceived size of stimulated body parts both at the site of stimulation and away from the site of stimulation, improved detection of near threshold tactile events. The mechanisms underlying this improvement were however found to be different across these conditions. While increasing perceived finger size at the site of stimulation altered response criterions, increasing and decreasing perceived hand size (away from the point of stimulation) improved perceptual sensitivity and also biased participants to positively report feeling the tactile stimulus.

5.10 Experiment 3

Given that similar mechanisms drove the increase in tactile perception during the stretched and shrunken hand conditions, Experiment 3 sought to explore how manipulating perceived finger size in either direction would affect near threshold tactile perception, and the mechanism underlying participants' responses.

Furthermore, while Kennett et al. (2001) suggested that when visual detail of the body surface is increased, tactile perception increases commensurately, their study did not include any control minified representations of the body part, therefore findings of Experiment 3 would also be useful in further validating and extending their suggestions. Here, participants completed the SSDT under the influence of three multisensory illusions; stretched finger, shrunken finger and detached finger as well as a veridical-baseline condition in which no illusion was applied. Tactile detection was predicted to increase during the stretched finger condition compared to the veridical-baseline condition (Kennett et al., 2001; de Vignemont et al., 2005; experiments 1 and 2). Shrinking the finger was expected to result in a significant reduction in tactile perception compared to baseline (in line with Kennett et al., 2001) or lead to no difference in tactile perception (along with the findings of de Vignemont et al., 2005). Given the stringent response criterions observed for the detached condition in Experiment 2, this condition was again included and expected to reduce tactile reports. These predictions were tested *a-priori* using direct comparisons between SSDT responses during the veridical-baseline condition and the three multisensory illusions; however, as in the previous study Bonferroni pairwise comparisons across all conditions are also reported where appropriate.

A subclinical MUS population studied by Miles, Poliakoff and Brown (2011) reported reduced susceptibility towards the RHI in which top-down knowledge regarding the body representation is altered by bottom-up visuo-tactile sensory information. Although differing in the type of distortions induced (*i.e.,* limb embodiment versus size and shape distortions) similar processes maybe thought to operate in illusions employed in this study whereby congruent visuo-proprioceptive stretching/shrinking of the finger alters the appearance of the finger. Consequently,

the current study explored the relationship between illusion strength and tendencies towards MUS (as measured by the Somatoform Dissociation Questionnaire-20; SDQ-20) with the aim of extending these previous findings to somatic illusions generated using the MIRAGE system. This scale has been identified as a proxy measure of tendencies towards medically unexplained symptoms (SDQ-20; Nijenhuis, Spinhoven, Van dyck, Der hart & Vanderlinden, 1996; Maaranen et al. 2005). Given previous findings, greater tendencies towards MUS were expected to be associated with reduced illusion strength (Brown, 2004; Miles et al., 2011) ratings in this study.

As discussed in Chapter 2, false-alarms on the SSDT, particularly in the presence of the task irrelevant light closely mimic somatosensory distortions and similar processes are thought to be operating in both cases. Previous studies have reported elevated self-reported MUS (measured using the SDQ-20) to be associated with increased false-touch reports on the SSDT (Brown, Brunt, Poliakoff & Lloyd, 2010) thus providing evidence for a link between unexplained symptom reporting and distorted somatic experiences on the SSDT. Thus far however, empirical evidence estimating the strength of this relationship is lacking, therefore, as a secondary aim the current study also examined this link whilst controlling for variables including SSAS and STAI-T. In line with previous studies (Brown et al., 2010) false-alarms were predicted to increase with SDQ-20 scores. As a result of the elevated false-touch reports, a negative relationship between response criterions and SDQ-20 scores were expected.

5.11 Experiment 3 Method

5.11.1 Participants

Thirty one right-handed (Oldfield, 1971) participants (10 male) aged 18 to 26 years (mean age=19.55; SD=1.31) were recruited. Written informed consent was obtained prior to participation and none of the participants reported any sensory deficits. Participants were compensated with 1 course credit (psychology students) or RM8.

5.11.2 Apparatus and Material

a) Questionnaire measures

As in Experiments 1 and 2, the trait anxiety index from the state-trait anxiety inventory and somatosensory amplification scale were used to control for negative affect and tendencies of amplifying ambiguous sensory information respectively.

Somatoform dissociation questionnaire: The Somatoform dissociation questionnaire (SDQ-20, Nijenhuis et al., 1996; Maaranen et al. 2005) was used to assess the self-reported likelihood of developing unexplained symptoms. Each question described symptoms such as “My body or part of it feels numb” and participants rated the degree to which each symptoms applied to them in the past year, on a 5 point Likert scale (where 1= not at all and 5=extremely). Total scores ranged from 20 to 100 with 20 indicating no experience of any of the listed symptoms.

Acclimatisation and illusion strength and hand ownership questionnaires were administered to assess ownership towards a video image of the hand and the extent to which each multisensory illusion and the veridical baseline condition was incorporated into participants’ body representation respectively. In addition to illusion strength and ownership questionnaires corresponding to the stretched finger and

detached finger conditions, a questionnaire that assessed how strongly participants felt the shrunken finger illusion ("I felt like my finger was really being shrunken") and participants' sense of ownership towards this distorted appearance of their hand ("I feel like I am watching myself") was included.

b) MIRAGE system

The stretched finger and detached finger conditions were conducted following the same procedure as that described in Experiment 1 and 2. During the shrunken finger condition, participants' index finger was gently 'pushed' while they simultaneously watched their finger shrink (see Figure 5.7a-d).

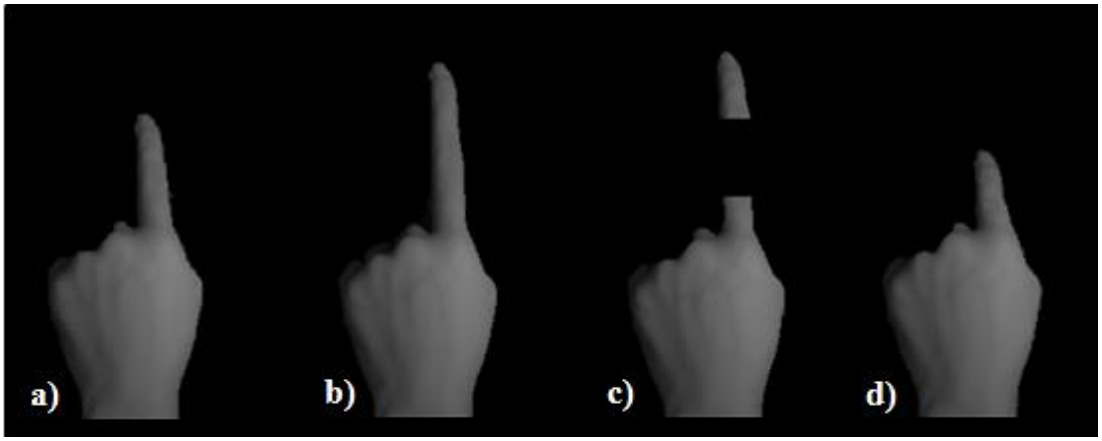


Figure 5.8a-d: Multisensory illusions and veridical baseline condition: (a) Veridical baseline (b) Stretched finger, (c) Shrunken finger, (d) Detached finger

c) Somatic signal detection task

The experimental setup was identical to Experiments 1 and 2. A tactile threshold (as described in experiment 1) was found for each participant after which the experiment proper was conducted. Experiment proper consisted of four blocks of 80 trials – each corresponding to one of the four experimental conditions (veridical-baseline stretched finger, shrunken finger and detached finger). Four different trial types (vibration only, vibration plus light, light only and catch-no stimulus) were

presented 20 times in a random order in each block and participants indicated whether or not they felt the vibration using “yes” and “no” responses.

5.11.3 Design and Procedure

This study used a 4 X 2 X 2 repeated measures design in which condition (veridical baseline, stretched finger, shrunken finger, detached finger), light (present, absent) and vibration (present, absent) were within-participant variables and the participant’s responses “yes”, and “no” were the dependent variables. The procedure was identical to that of Experiment 2, with the veridical baseline condition being conducted first and followed by the rest of the illusion conditions in a counter balanced order.

5.12 Experiment 3 Results

5.12.1 Questionnaire responses

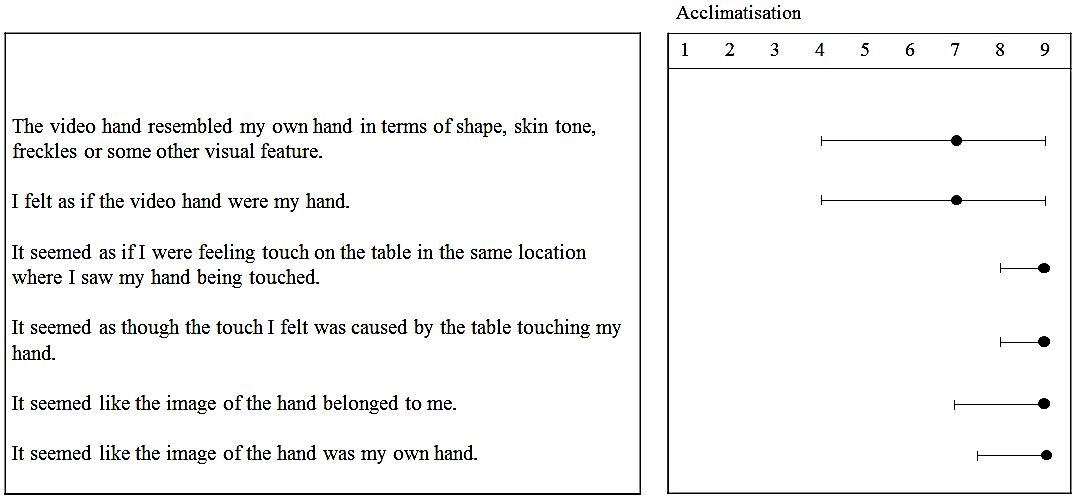
All questionnaire ratings remained not normally distributed following attempts to transform the data (Shapiro Wilk statistic showed that $p<.05$) consequently, non-parametric analyses were conducted.

Acclimatisation questionnaire: In line with Experiments 1 and 2 responses to this questionnaire showed a strong sense of ownership towards the video image of the hands. Participants strongly agreed with statements such as ‘*It seemed like the image of the hand was my own’* (Median= 9) and *‘It seemed like the image of the hand belonged to me’* (Median= 9; Figure 5.8a).

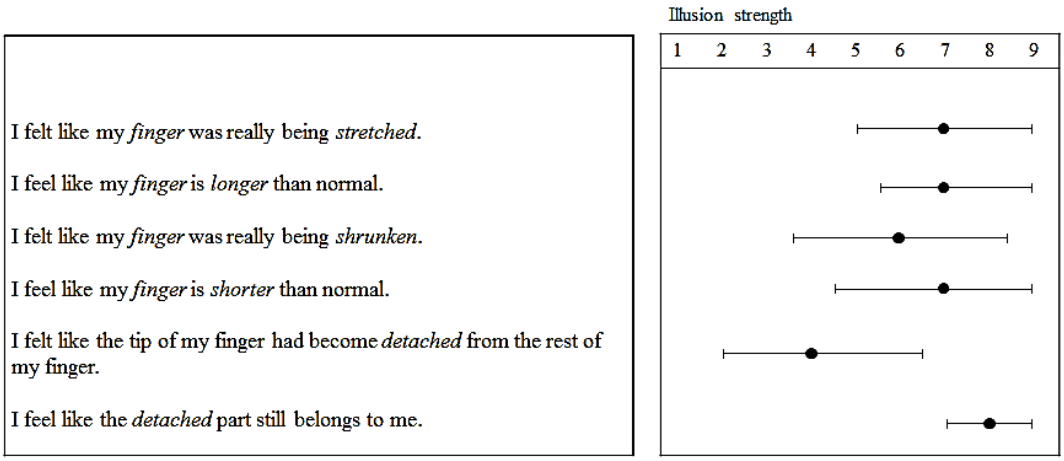
Illusion strength and hand ownership questionnaires: In line with Experiments 1 and 2 ownership ratings indicated that participants strongly agreed that the video image of the hand belonged to them in all conditions whereas illusion strength ratings

indicated that participants felt the detached finger condition the least (see Figures 5.8b-c).

a) Acclimatisation



b) Illusion strength statements



c) Ownership statements

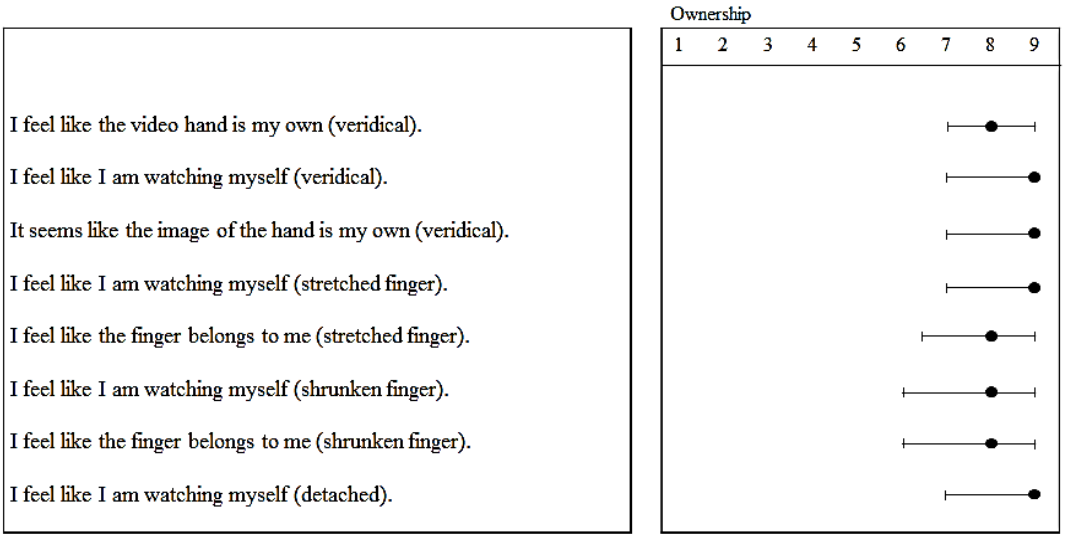


Figure 5.9a-c: Medians and inter-quartile ranges for questionnaire ratings: (a) Acclimatisation (b) Illusion strength statements (c) Ownership statements

Mean illusion strength ratings were separately calculated for the stretched finger and shrunken finger conditions by averaging ratings to the statements *'I felt like my finger was really being stretched/shrunken'* and *'I feel like my finger is longer/shorter than normal'*. Ratings to the statement *'I feel like the detached part still belongs to me'* was reverse scored and averaged with ratings to the statement *'I felt like the tip of my finger had become detached from the rest of my finger'* to obtain mean illusion strength ratings for the detached condition. Mean illusion strength ratings were then compared across the three conditions. A Freidman's ANOVA revealed significant differences in illusion strength between the three illusion conditions (χ^2 (2, N=31) = 11.78, *p*=.003). Wilcoxon signed-ranks tests (with a Bonferroni corrected significance level of .016) indicated higher illusion strength ratings when the finger felt to be stretched (Median= 7) compared to when it felt to be detached (Median= 4; Z= 3.42, *p*=.001, r=.61). Illusion strength was also higher when the finger was shrunken (Median= 6) compared to when it was detached (Median= 4;

Z= 2.81, *p*=.005, r=.50). No difference in illusion strength was seen between the stretched (Median=7) and shrunken (Median=6) conditions (Z= -.87, *p*=.38). The statement *'I feel like I am watching myself'* indicated sense of ownership in all four conditions (illusion and veridical baseline). A Freidman's ANOVA conducted on ownership ratings to this statement revealed no significant difference between the three multisensory illusions or the baseline condition (χ^2 (2, N=31) = 4.73, *p*=.19).

5.12.2 SSDT parameters

As in Experiments 1 and 2, hit rates and false-alarm rates were used to the calculate signal detection theory test statistics; sensitivity (*d'*) and response criterion (*c*). Descriptive statistics for hit rates, false-alarm rates, sensitivity and response criterion across all conditions are summarised in Table 5.3 below.

Table 5.3: Mean (and standard deviations) of hit rates, false-alarm rates and signal detection statistics of each condition in the presence and absence of light

Condition	Hits (%)	False-alarms (%)	*d'*	*c*
Veridical				
Light	53.1 (17.10)	28.34 (19.59)	0.76 (0.57)	0.28 (0.48)
No light	44.47 (17.52)	21.43 (16.08)	0.74 (0.63)	0.53 (0.41)
Stretched finger				
Light	61.54 (12.77)	30.49 (22.52)	0.95 (0.83)	0.15 (0.44)
No light	51.38 (20.28)	27.23 (20.66)	0.75 (0.76)	0.33 (0.50)
Shrunken finger				
Light	62.75 (17.36)	25.58 (18.06)	1.12 (0.83)	0.21 (0.37)
No light	57.53 (21.95)	21.58 (18.70)	1.19 (0.98)	0.36 (0.60)
Detached finger				
Light	52.00 (15.39)	22.20 (20.50)	1.03 (0.91)	0.46 (0.41)
No light	41.09 (15.29)	16.21 (15.71)	0.94 (0.74)	0.72 (0.42)

A series of 2 x 4 repeated measures ANOVAs with light (2; present and absent) and condition (4; *i.e.*, veridical-baseline, stretched finger, shrunken finger and detached finger) as within subject factors were conducted on hit rates, false-alarm rates, tactile sensitivity (*d'*) and response criterion (*c*).

Hit rates

Hit rates were significantly higher in the presence of light ($F_{(1,30)=}$ 32.27, $p<.001$, $\eta_p^2= .52$). A significant main effect of illusion condition was also seen ($F_{(3,90)=}$ 6.83, $p<.001$, $\eta_p^2=.19$). Planned comparisons revealed significantly higher hit rates in the stretched finger condition compared to the veridical baseline condition ($F_{(1,30)=}$ 5.58, $p=.025$, $\eta_p^2=.16$). Hit rates were also significantly higher in the shrunken finger condition compared to the baseline condition ($F_{(1,30)=}$ 9.82, $p=.004$, $\eta_p^2=.25$), however, no difference was seen between the detached finger condition and veridical baseline condition ($F_{(1,30)=}$ .38, $p=.54$). Pairwise comparisons revealed significantly greater hit rates during stretched finger condition compared to the detached condition (mean difference =.099, $p=.014$) as well as during the shrunken finger condition compared to the detached condition (mean difference =.14, $p=.009$) however, no significant differences in hit rates were revealed during the stretched finger compared to the shrunken finger condition (mean difference =.037, $p=.99$). Light and condition were not found to interact ($F_{(3,90)=}$ .65, $p=.59$). The findings remained the same when controlled for STAI-T and SSAS.

False-alarm rates

False-alarm rates were not normally distributed, a square root transformation was therefore applied to normalise the data. In the presence of the light false-alarm rates were found to be significantly higher overall ($F_{(1,30)}$= 12.70, $p=.001$, $\eta_p^2=.30$). A

significant main effect of condition was also found ($F_{(3,90)}$= 6.20, p=.001, η_p^2=.17). Planned comparisons revealed significantly lower false-alarm rates in the detached finger condition compared to the veridical baseline condition ($F_{(1,30)}$= 7.49, p=.010, η_p^2=.21). No differences were seen between the stretched and veridical-baseline conditions ($F_{(1,30)}$= 1.44, p=.24) as well as the shrunken and veridical-baseline conditions ($F_{(1,30)}$= .62, p=.44). Interestingly, pairwise comparisons revealed lower false-alarms during the detached compared to stretched finger condition (mean difference =.112, p=.001). No other differences across the illusion conditions were however found to be significant (all p>.05). The interaction between light and condition were also not significant ($F_{(3,90)}$=.76, p=.52). These findings remained the same when the STAI-T and SSAS were included as covariates.

Tactile sensitivity (d')

A main effect of illusion condition was found ($F_{(3,90)}$= 3.63, p=.016, η_p^2=.11). Planned comparisons indicated a significantly greater tactile sensitivity during the shrunken finger condition compared to the veridical baseline condition ($F_{(1,30)=}$ 9.41, p=.005, η_p^2=.24). A trend towards greater sensitivity was also seen during the detached condition compared to the veridical baseline condition ($F_{(1,30)=}$ 3.76, p=.062, η_p^2=.11). No difference between the stretched and veridical-baseline conditions were seen ($F_{(1,30)=}$ .86, p=.36). Pairwise comparisons revealed no significant differences between the rest of the illusion conditions (all p>.05).No main effect of light ($F_{(1,30)}$=1.09, p=.31), and no interaction was observed ($F_{(3,90)}$=.98, p=.41). No difference was found when the STAI-T and SSAS were included as covariates

Response criterion (c)

Response criterion was significantly lower in the presence of light, suggesting that participants were more likely to report feeling a vibration when the light was present ($F_{(1,30)}$= 29.27, p<.001, η_p^2=.49) – regardless of whether or not a stimulus had been present. A significant main effect of illusion condition was also seen ($F_{(3,90)}$= 7.79, p<.001, η_p^2=21); planned comparisons indicated that participants were more likely to report feeling the vibration during the stretched finger condition compared to the veridical baseline condition ($F_{(1,30)}$= 4.20, p=.049, η_p^2=.12). Participants were also significantly less inclined to report feeling the vibration during the detached finger condition ($F_{(1,30)=}$ 5.13, p=.031, η_p^2=.15), although there was no difference between the shrunken and baseline conditions ($F_{(1,30)=}$ 2.25, p=.14). In line with Experiment 2, stringent response criterions were also reported during the detached compared to the stretched finger (mean difference =.35, p<.001) as well as the shrunken condition (mean difference =.31, p=.003). No difference between the stretched and shrunken conditions was seen (mean difference =.038, p=1.00). Light and illusion condition were not found to interact ($F_{(3,90)}$=.39, p=.76). The difference between the stretched finger and veridical baseline condition was reduced to a strong trend ($F_{(1,27)}$= 4.00, p=.051, η_p^2=.13) when the STAI-T and SSAS were included as covariates.

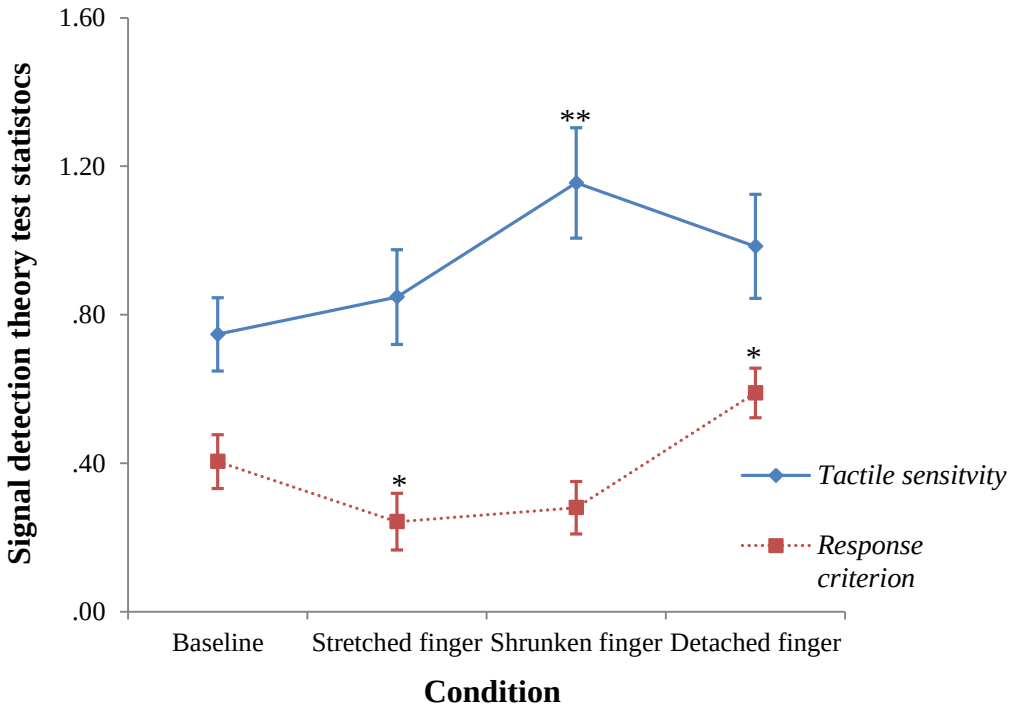


Figure 5.10: Mean tactile sensitivity (*d'*) and response criterion (*c*) for each condition. Error bars show standard error of the mean. Asterisks indicate the significant difference between the veridical baseline condition and illusion conditions (**p*< .05, ***p*≤.01)

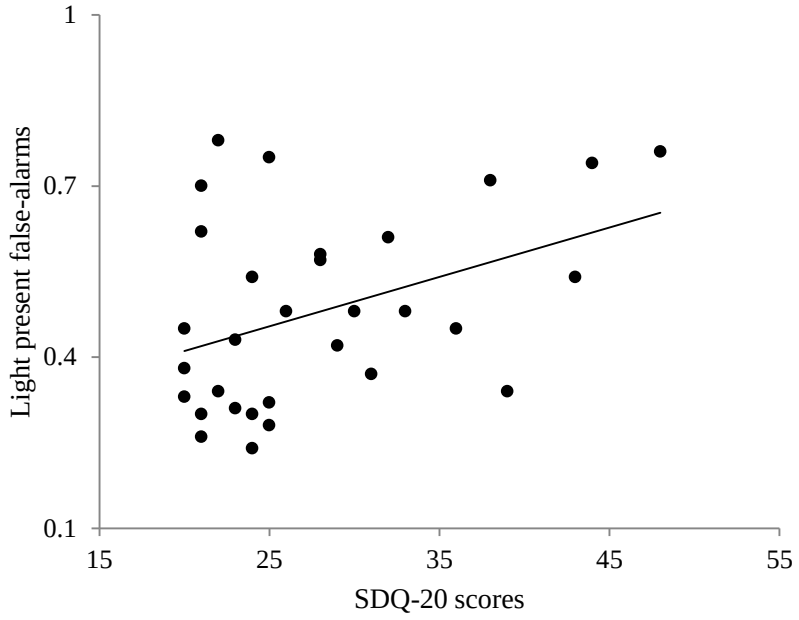
5.12.3 Correlation between self-reported MUS and SSDT parameters

Mean illusion strength ratings across the illusion conditions; stretched, shrunken and detached were correlated with SDQ-20 scores. No significant correlation between SDQ-20 scores and illusion strength were seen for the stretched ($r_{(31)}$= -.14, *p*=.46), shrunken ($r_{(31)}$=.052, *p*=.78) or detached finger ($r_{(31)}$=.19, *p*=.31) conditions.

A Pearson product-moment correlation was then conducted on all SSDT parameters (hit rates, false-alarm rates, *d'* and *c* collapsed across condition) in the presence and absence of light (as in Katzer, Oberfeld, Hiller & Witthöft, 2011; Brown et al., 2012). False touch reports were significantly positively correlated with SDQ

scores both in the presence ($r_{(31)}$=.41, p=.023; Figure 5.11a) and absence of the light ($r_{(31)}$=.53, p=.002; Figure 5.11b). A significant negative correlation was seen between sensitivity and SDQ scores in the presence ($r_{(31)}$=-.48, p=.006) and absence ($r_{(31)}$=.42, p=.019) of the task irrelevant light. No significant correlations were seen for hit rates or response criterion in the presence and absence of light (all p>.05). Hierarchical regressions were then conducted to investigate how well false-alarm rates in the presence and absence of the light predicted SDQ-20 scores while controlling for SSAS and STAI-T. These inventories were included in line with evidence suggesting that negative affect, anxiety (Watson and Pennebaker, 1989; Henningsen, Zimmermann & Sattel 2003) as well as amplification of benign somatic events (Barsky, 1992) are associated with tendencies towards MUS.

a) Light present false-alarms



b) Light absent false-alarms

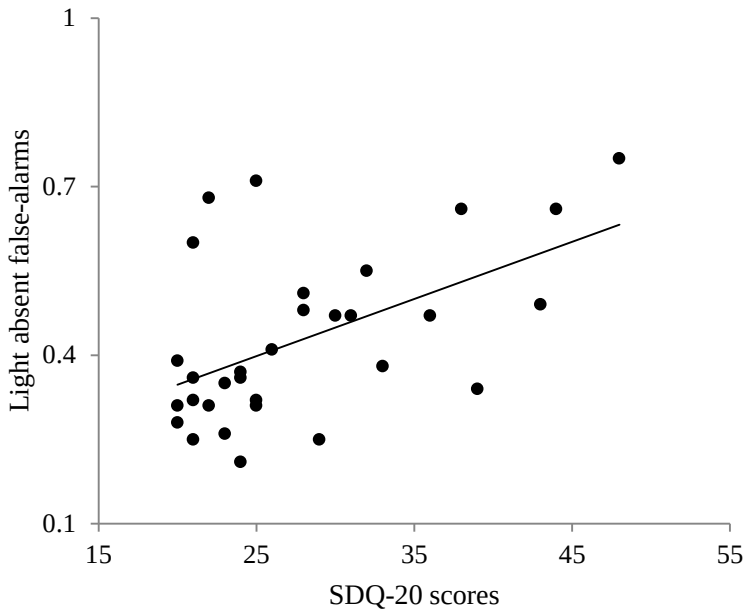


Figure 5.11a-b: Correlation between SDQ-20 and false-alarm rates: (a) Light present false-alarms (b) Light absent false-alarms

For the regression analysis, SDQ-20 scores were included as a dependent variable while SSAS and STAIT-T were included as covariates in step 1 and light present and absent false-alarms were separately included as predictors in step 2. Correlations between all predictor variables were not strong (ranging from r=.069 to r=.53) suggesting that multicollinearity was an unlikely problem. Light present false-alarms explained 16.5% of the variance in SDQ-20 scores and significantly improved the predictive power of the regression equation (R^2 Change = .165 $F_{(1,30)}$=5.75, p=.023) when controlling for SSAS, and STAI-T. Light present false-alarms were also found to be the only significant predictor of SDQ-20 scores (standardised β=.39, t=2.27, p=.032). Similarly light absent false-alarms significantly explained 28.1% of the variance in SDQ-20 while controlling for SSAS and STAI-T (R^2 Change = .281; $F_{(1,30)}$=11.31, p=.002). Here again light absent false-alarms were the only significant predictor of SDQ-20 scores (standardised β=.54, t=3.28, p=.003).

5.13 Experiment 3 Discussion

Experiment 3 examined the mechanisms by which manipulating perceived finger size altered near-threshold tactile detection using the SSDT. Illusory stretching and shrinking was expected to have different outcomes in terms of tactile perception. Instead, our findings suggested that both stretching and shrinking the finger significantly improved correct tactile perception. Interestingly, however, this effect was found to be driven by liberal response criterions and increased tactile sensitivity for the stretched and shrunken finger respectively, suggesting separate underlying mechanisms to be responsible for the improvement in tactile perception. As with Experiment 2 however, no differences in tactile sensitivity or response criterions were seen between the two conditions, perhaps indicating some level of overlap in the mechanisms underlying the increase. The absence of any significant increase in false touch reports during the stretched condition suggests that the observed differences in response criterion could be largely attributed to the increase in hits, rather than to a general tendency towards reporting positively across all trials. The liberal response criterion seen during the stretched finger condition reduced to a strong trend when relevant covariates were included. This covariance provides evidence for the suggested overlap between somatosensation and subjective judgements of trait anxiety/negative effect (Watson & Pennebaker, 1989) and tendencies towards increased somatic sensitivity in individuals (Barsky et al., 1988). Similar behavioural outcomes during the stretched and shrunken finger may rule out suggestions of Kennett et al. (2001) and possible reasons for our findings are discussed in the general discussion. Furthermore, illusion strength and ownership ratings were found to be high and no differences in ownership were found between the two conditions

suggesting that although participants strongly felt their finger being stretched and shrunken ownership was not lost as a result of these multisensory illusions.

False touch reports were found to be significantly lower during the detached finger condition. In line with Experiment 2, response criterions were also more stringent for this condition – indicating that participants were less likely to report feeling the vibration. Illusion strength was reduced for this condition and ownership was still claimed over the detached finger, perhaps due to different techniques utilised to measure ownership such as skin conductance responses (Newport & Preston, 2010) or differences in the types illusions/manipulations employed for body discontinuity (Perez-Marcos et al., 2011; Tieri et al., 2015).

Inclusion of the simultaneous task irrelevant light significantly increased correct detection of the vibration (hit rates). False-alarm rates were also found to be significantly higher in light present trials. The increase in both hit and false-alarm rates in light trials could be attributed to the liberal response criterions in the presence of light. This finding is also in line with previous results (Johnson et al., 2006; Lloyd et al., 2008; McKenzie et al., 2010; Mirams et al., 2010) and suggests that concurrent visual information is incorporated into decisions about ambiguous somatic events, even when such visual information is entirely task-irrelevant.

False-alarm rates were significantly positively correlated with SDQ-20 scores both in the presence and absence of light, thus providing evidence for the proposed link between self-reported MUS and the tendency to experience somatosensory distortions as measured by false-touch reports on SSDT (Brown et al., 2010). Interestingly, significant negative correlations were also found between tactile sensitivity on the SSDT and self-reported MUS scores, suggesting that the propensity to develop unexplained somatic symptoms is associated with an inability to

differentiate between signal and noise (Rief & Barsky, 2005). Light present and absent false-alarms also significantly improved the predictive power of the regression equation in each case, and were the most significant predictors of SDQ-20 scores. While false-alarms have been previously suggested to act as laboratory analogues of MUS, the current finding provides the first known evidence for the strength of this link and extends these previous findings by suggesting that tendencies to misperceive somatic events predict self-reported tendencies towards MUS even when controlled for negative affect and somatosensroy sensitivity. No significant correlation was seen between SDQ-20 scores and illusion strength ratings for the stretched, shrunken or detached finger conditions. Although individuals with increased tendencies towards MUS have previously been found to be less susceptible to illusions such as the RHI (Miles et al., 2011) which involved embodiment of an artificial limb following discrepant sensory input, illusions used in the current study only manipulated perception of the finger, thus suggesting that the nature of the illusions employed may be important in determining illusion susceptibility of individuals with tendencies towards MUS.

In summary, Experiment 3 contributed to the growing body of evidence investigating the link between perceived body size and tactile detection (Kennett et al., 2001; de Vignemont et al., 2005) by demonstrating that manipulating body size at the site of stimulation has similar behavioural outcomes in terms of tactile perception. These improvements are, however, governed by different underlying mechanisms. Finally, the study also provided evidence for a robust link between self-reported unexplained symptoms and somatosensory dissociation.

5.14 General discussion

The three studies described in this Chapter investigated how manipulating body perception through visuo-proprioceptive illusions can alter near-threshold tactile perception. Although altering perceived body size was expected to lead to different response patterns on the SSDT, the overall results demonstrated an improvement in correct tactile detection following both an increase and decrease in perceived body size, both at the site of stimulation and away from the site of stimulation. Furthermore, whilst in previous studies the precise mechanisms underlying changes in tactile perception as a result of alterations to perceived body size have been unclear, the current findings demonstrate that, for tactile detection at least, similar behavioural outcomes following altered body representations can in fact be driven by separate processes. In contrast to two-point discrimination tasks used in previous studies (de Vignemont et al., 2005), the current studies involved detection of near threshold tactile stimuli with no spatial component which may have led to the observed difference. Indeed, perception of both above threshold tactile stimuli with spatial components and near threshold tactile stimuli with no spatial component has been reported to be different perhaps due to differences in task difficulty (Press, Taylor-Clarke Kennette & Haggard 2004). In line with previous studies (Kennett et al., 2001; de Vignemont et al., 2005) increasing perceived body size at the site of stimulation during the stretched finger condition improved correct tactile detection across all three experiments, which could be attributed to the liberal response criterions observed. Visuo-proprioceptive stretching of the finger may have temporarily alter cortical processing and increase activation of the visuo-tactile bimodal neurones in parietal regions, resulting in increased tactile perception (Kennett et al., 2001; Schaefer, Flor, Heinze, & Rotte, 2005; 2006). Indeed, there is evidence suggesting that visuo-tactile

interactions are linked to primary somatosensory cortex modulations which have dense connections with the parietals areas (Zhou & Fuster, 1997; Schaefer, Heinze & Rotte, 2005b). Contrary to expectations, however, the shrunken finger also improved correct tactile perception; as a result of increased tactile sensitivity. During this condition, it is possible that the increased tactile sensitivity was due to a perceived reduction in visual area of the finger; this may have resulted in a lower weighting of the incoming visual signal, causing a shift in sensory weighting (Ernst & Banks, 2002) toward information unrelated to the appearance of the hand - which in this case was tactile information. Alternatively, given our constant exposure of our limbs growing in size, the shrunken condition may have been perceived negatively, leading to anxiety and stress. This would have increased firing of noradrenergic neurons (found to be associated with vigilance, alertness and selective attention to meaningful or novel stimuli; Southwick et al., 1999; Steimer, 2002) in the locus ceruleus, resulting in greater tactile sensitivity during this condition. In line with this, delusions of excessive body size are more commonly reported in psychiatric and neural conditions (Frederiks, 1963; Mauguiere & Courjon, 1978; Leker, Karni & River, 1996; Robinson & Podoll, 2000), while experimental studies have sometimes reported asymmetric tendencies of ownership towards veridical and enlarged representations of the body (Ramachandran & Rogers-Ramachandran, 1996; Pavani & Zampini, 2007; Haggard & Jundi, 2009) suggesting that enlarged representations are perhaps perceived more positively. These findings should however be interpreted with caution, as no differences in tactile sensitivity or response criterions were evident between the stretched and shrunken conditions. Therefore, the idea that the shrunken finger condition may have altered corresponding cortical regions cannot be completed ruled out (Schaefer et al., 2006), thus suggesting an overlap in the effects exerted by

illusory resizing of a body part. Future studies should therefore aim to disentangle these differing causes using neuroimaging techniques that examine the neural pathways responsible across different response patterns under the various illusion conditions.

Altering perceived body size away from the point of stimulation also improved tactile detection, regardless of the direction in which perceived body size was altered. Interestingly, similar processes were found to underlie this improvement. Previous studies have consistently reported that increased attention towards somatic information raises awareness of subtle internal bodily sensations such as internal pulse sensations (Haenen, Schmidt, Kroeze & van den Hout, 1996; Moss-Morris, Sharon, Tobin & Baldi, 2005) which may create uncertainty in somatic decision making and therefore lead to misperceptions or misinterpretations of benign somatic events or experiences (Rief & Barsky 2005; Deary, Chalder, & Sharpe, 2007; Rief & Broadbent, 2007). These findings, may therefore suggest that the stretched and shrunken hand conditions would have directed attention away from the stimulation site and as a result reduced interference from distracting internal bodily sensations, thus resolving ambiguity of the tactile stimulus. Here again, no differences were seen in signal detection theory test statistics across the illusion conditions, again suggesting a potential overlap in the mechanisms driving the increase in hit rates. While we believe that the stretched and shrunken hand may have directed attention away from the site of stimulation thus reducing ambiguity of the incoming tactile signal, it cannot be ruled out that the illusions still altered primary somatosensory cortex regions (Schaefer et al., 2006).

When the finger appeared to be detached, false touch reports were found to be significantly lower and response criterions were also more stringent for this condition.

During this condition, tactile attention may have been focused on the tip of the finger that appeared to be disconnected from the rest of the body rather than on whole finger more generally. This would have limited the influence from distracting internal bodily sensations as body focused attention has been shown to increase awareness of internal bodily sensations (Rief & Barsky 2005; Deary et al., 2007; Rief & Broadbent, 2007), which in the other conditions could be confused with the SSDT vibration. This may have had the effect of reducing tactile 'noise' and the ambiguity of the tactile signal in the detached condition, especially during vibration absent trials. Surprisingly, ownership was still claimed over the detached finger and illusion strength ratings indicated that participants felt this illusion the least. Nevertheless, this finding indicates that participants' responses were influenced by the detached appearance of the finger and suggests that somatosensation may be guided by the visual appearance of a body part. Indeed, visual input of a body part has been found to alter tactile perception (Moseley & Wiech, 2009) even after visual input has been removed (Taylor-Clarke, Kennett, Haggard, 2004; Ro, Wallace, Hagedorn, Farne, Pienkos, 2004) suggesting that such effects may induce long-term changes. It is not clear why ownership was still claimed during this illusion condition given that previous studies have continuously reported perceived discontinuity to result in reduced ownership over a body part (for example; Newport & Preston, 2010; Perez-Marcos et al., 2011; Tieri et al., 2015), however, it should be noted that these previous studies measured ownership either when a body part was missing (*e.g.*, the wrist, the forearm; Perez-Marcos et al., 2011; Tieri et al., 2015) rather than following disconnection or by using different (objective) techniques such as the time taken to elicit a virtual hand illusion (Perez-Marcos et al., 2011) or skin conductance responses (Newport & Preston, 2010). Newport and Preston (2010) used a similar illusion to that of the current study;

however, ownership was assessed using skin conductance responses following virtual stabbing of the finger. This finding should therefore encourage future studies to obtain objective measures when assessing sense of ownership.

Previous studies using the SSDT have shown vision of the hand to increase false touch reports when it was non-informative, that is when no additional helpful information about touch was provided (Mirams et al., 2010). This finding is in agreement with clinical models of MUS that have suggested increased body focused attention to increase awareness of benign internal bodily sensations (Rief & Barsky 2005; Deary et al., 2007; Rief & Broadbent, 2007) that could be confused with the SSDT vibration (Mirams et al., 2010). The current findings therefore suggest that such an effect can be modulated by manipulating perception of the body through multisensory illusions. These findings are in line with studies that have shown pain perception to be modulated by manipulating the visual appearance of the hand (Ramachandran, Brang and McGeoch, 2009; Mancini et al., 2011; Preston & Newport, 2011) independent of the influence of pure response bias effects (Romano and Maravita 2014).

Experiment 3 added to previous literature by also finding self-reported MUS scores (SDQ-20) to be positively correlated with light present and absent false touch reports. In line with this Brown et al. (2010) found higher scorers on the SSDT to report significantly more false-touch reports. While this correlation suggests similar underlying mechanisms for light present and absent false touch reports, it also extends previous studies that have shown false-alarm rates in light present and absent conditions to involve similar brain regions (Lloyd, McKenzie, Brown & Poliakoff, 2011) and be affected by prior training (McKenzie, Lloyd, Brown, Plummer & Poliakoff, 2012). Self-reported MUS were also negatively correlated with sensitivity

indices in light and no light conditions, suggesting that tendencies towards MUS are associated with difficulty in filtering out irrelevant somatic sensations (Rief & Barsky, 2005) or in this case sensory 'noise'. Moreover, while previous literature has provided evidence for the strength of the relationship between false-alarms and physical symptom reporting (Katzer et al., 2011; Brown et al., 2012), studies examining the strength of the relationship between MUS and false-alarms is lacking. The current finding addresses this gap and provides evidence for a link between somatoform distortions as measured by false-alarms on the SSDT and self-reported unexplained symptoms by suggesting that tendencies to false-alarm on the SSDT may in fact be indicative of propensities towards MUS.

In summary, the current findings highlighted the plasticity and flexibility of the internal body image and suggest that somatosensation can be modulated by distorted representations of the body. While different underlying mechanisms may operate in interpreting somatic experiences when information relating to the size of the body at the site of stimulation is altered, similar processes are responsible for altered somatic experiences following manipulations to perceived body size (away from the site of stimulation). The current findings may also be clinically relevant for treatment programs aiming to relieve chronic pain. Most chronic pain states are associated with distorted perceptions of the body (Haigh, McCabe, Halligan, Blake, 2003) and sensory discrimination training has been found to resolve pain (Moseley et al., 2008; Moseley & Wiech, 2009) particularly when participants look at the stimulated body part (Moseley & Wiech, 2009). The current results may therefore suggest that perhaps, pairing sensory discrimination training with body size altering illusions would provide valuable insight into the nature of distortions associated with chronic pain which may in turn lead to more sustained improvements. Finally, the

relationship between unexplained symptoms and false-alarms support the proposed hypothesis that MUS stem from disrupted perceptual processes (Rief & Barsky, 2005). Further investigations into this association may lead to the development of well targeted intervention programs for MUS.

The current chapter provided interesting evidence of the role of visuo-proprioceptive size altering illusions on tactile perception and the mechanism driving these effects. Internal bodily sensations were thought to be responsible for the varied effects across some of the illusions. Chapter 6 therefore aimed to expand upon this and further examine the role of increased interoception on somatosensation in both clinical and subclinical populations (assessed using the SDQ-20). Moreover, while illusions incorporated in the current chapter were multisensory by nature the study reported in Chapter 6 examined how tactile perception would be altered following illusions that are purely visually induced.

CHAPTER 6

DOES VISUALLY EVOKED SOMATOSENSATION INTERFERE WITH SOMATIC SENSATIONS?

Abstract

Awareness of internal somatic sensations has been shown to interfere with external tactile perception and is also thought to largely contribute to medically unexplained symptoms (MUS). This study aimed to objectively examine the influence of increased interoceptive awareness on somatic perception using a novel visual illusion that generated internal somatic sensations on the skin (in the absence of real sensory input). The study also compared response patterns of individuals with an increased propensity to develop MUS to those who are less likely to do so. Participants responded to near threshold vibrations on their index finger whilst watching the visual illusion, as well as during two control conditions; a veridical baseline condition and a darkened condition (that matched the brightness level of the illusion). Overall, no differences in response patterns were seen across the three conditions and possible reasons for this are discussed in relation to a Modality Shift Effect (MSE) or reduced salience of the illusion. There was also no association between tendencies towards MUS and responses to tactile perception across the different conditions thus encouraging future studies to be cautious of the nature of the illusions employed when examining such individual differences. Nevertheless, the findings, aid the understanding of the psychological processes underlying MUS.

6.1 Introduction

Body focused attention is a major determinant of somatosensation. Indeed, attentional manipulations towards a body part have been found to alter somatic sensations in that region. For example, visual attention towards the hand has been found to increase false-alarms on the Somatic Signal Detection Task (SSDT; Lloyd, Mason, Brown & Poliakoff, 2008) in the presence of the task irrelevant light compared to when no vision of the hand was available (Mirams, Poliakoff, Brown & Lloyd, 2010). This interaction between vision and light is thought to be a result of the light attracting attention to the body and bringing to awareness previously unperceived internal bodily sensations (such as internal pulse sensations of the finger), that may be confused with the vibration in the SSDT (Mirams et al., 2010). In line with this, further studies have demonstrated that changing the direction and nature of internal body focused attention has been found to differently alter somatosensation. For example, increasing sensory noise by making participants attend to internal pulse sensations at their finger-tip has been found to result in more liberal response criterions (Mirams, Poliakoff, Brown & Lloyd, 2012) perhaps as a result of such sensations being confused with the SSDT vibration (Mirams et al., 2012). On the other hand, attending to more external information relating to the body (using a grating orientation task) reduced false-alarm rates and resulted in stringent response criterions possibly by reducing any interference from confusing internal bodily sensations (Mirams et al., 2012). Together these findings suggest that our somatic experiences are influenced and shaped by top-down factors such as attention that increases interoceptive awareness and lead to misperceptions.

Attending to internal somatic sensations has also been found to lead to unexplained physical symptoms better known as medically unexplained symptoms

(MUS). Traditional clinical models have suggested MUS to be a result of excessive body focused attention bringing to awareness benign bodily sensations that are then misinterpreted as serious illnesses (Sharpe, Peveler & Mayou, 1992; Rief, Hiller & Margraf, 1998). More recent models have suggested selective attention to lead to MUS either via a process of over-arousal or filtering deficits (Rief & Barsky 2005; Deary, Chalder & Sharpe, 2007; Rief & Broadbent, 2007). Another recent model suggests that symptom related information could be activated by excessive body-focused attention among other factors (Brown, 2004). Consistent with these models, patients with unexplained physical complaints are generally found to be more aware of their internal bodily sensations and show a bias towards perceiving these sensations as being more threatening and intense, resulting in them being identified as more serious physical illnesses. For example, Duddu, Chaturvedi and Isaac (2003) found patients with somatoform disorders to report more symptom experiences, show greater somatic preoccupation, report excessive illness worry and greater fear of having or developing a disease, compared to patients with depressive disorders and healthy controls. Such patients are also found to report more illness beliefs and display greater symptom expression even when controlling for age and gender (Rief, Nanke, Emmerich, Bender & Zech, 2004). Despite making more illness attributions, patients with somatoform symptoms are usually less accurate on tasks that objectively measure internal bodily sensations (Mussgay, Klinkenberg & Ruddel, 1999). For example, patients who seek medical help for benign palpitations perform poorly on heart-beat perception tests and show greater prevalence of panic attacks compared to patients with clinically significant arrhythmias (Ehlers, Mayou, Sprigings & Birkhead, 2000). In addition, although highly aware of somatic sensations, patients with greater illness worry were not more accurate on tactile two-point discrimination tasks

compared to healthy controls (Haenen, Schmidt, Schoenmakers & van den Hout, 1997).

While the studies discussed above have examined the perceptual effects of interoceptive awareness using objective tasks that increased awareness of internal bodily sensations (*e.g.*, internal pulse sensations), this study aimed to examine whether visual illusions that suggest interoceptive sensations on the skin in the absence of real somatosensory input could also result in similar perceptual effects. Furthermore, in comparison to previous somatic illusions that were dependent upon bottom-up and top-down processes (*e.g.*, Rubber hand illusion; RHI- Miles, Poliakoff & Brown, 2011) the current illusion exerted purely top-down effects on somatic sensations and thus provided a means of investigating the link between disproportionate top-down reliance and dysfunctional somatic perception in MUS. The visual illusion created a moving-pixelated appearance on the skin and was previously found to raise awareness of more ambiguous internal bodily sensations (McKenzie & Newport, 2015) thus creating illusory somatic sensations in participants. The current study therefore examined how such internal illusory somatic sensations would interfere with external bottom-up somatosensation. Somatic sensations were assessed using a modified version of the SSDT which did not include the light – this was so that the effect of the visual illusion on somatic perception could be investigated without the potentially confounding presence of the task irrelevant light (previously found to alter attention to the hand) as well as to avoid the possibility of reduced visibility of the visual stimulus as a result of the pixelated nature of the illusion. It was therefore expected that the illusory somatosensations during the pixelated illusion would increase sensory noise (compared to control conditions) and lead to misperceptions of the SSDT stimulus, thus resulting in increased perceptual

errors (false-alarms) and liberal response criterions (Mirams et al., 2012). Secondly, the association between SSDT parameters across the different visual conditions (illusion and control) and self-reported tendencies towards MUS (measured using the SDQ-20; Nijenhuis, Spinhoven, Van dyck, Der hart & Vanderlinden, 1996) were examined. Previous studies have demonstrated that susceptibility to somatic illusions reflect individual differences in tendencies towards experiencing somatic distortions. For instance, susceptibility to vibration induced illusory arm extensions has been found to correlate with frequency of body schema distortions in everyday life in healthy participants (Burrack & Brugger, 2005) while increased propensities towards MUS are found to be associated with reduced embodiment of the fake limb during the RHI (Miles et al., 2011) as well as reduced ownership during the pixelated illusion (McKenzie & Newport, 2015). Given the top-down nature of the illusion, it was hypothesised that individuals with increased tendencies toward to MUS would display increased susceptibility and hence experience more illusory somatic sensations leading to increased false-alarms and liberal response criterions on the SSDT. However, in line with McKenzie and Newport (2015) reduced ownership over the limb during the pixelated illusion condition was expected, in comparison to the control conditions.

6.2 Method

6.2.1 Participants

Thirty right handed (Oldfield, 1971) participants (18 female) aged 18 to 27 years (mean age=20.56; S.D=2.29) from the University of Nottingham Malaysia campus were recruited. Written informed consent was obtained prior to participation.

All participants were of normal or corrected to normal vision, and reported no sensory deficits. Participants were compensated with 1 course credit or RM 8.

6.2.2 Apparatus and Material

a) Questionnaire measures

Somatoform dissociation questionnaire: As in chapter 5 the SDQ-20 (Nijenhuis, et al., 1996; Maaranen et al. 2005) was used to assess the self-reported likelihood of developing unexplained symptoms. Participants rated the degree to which each symptom applied to them in the past year, on a 5 point Likert scale (where 1= not at all and 5=extremely).

As in the previous chapters the acclimatisation questionnaire (Newport, Pearce & Preston, 2010) was used to assess sense of ownership towards the video image of the hand in its actual location prior to the illusions. Ownership questionnaires were used to measure participants' sense of ownership towards the distorted appearance of their hand (*e.g.,* 'I feel like I am watching myself'). During both acclimatisation and ownership questionnaires, participants made verbal judgments on a 9 point numeric rating scale in which 9 indicated strong ownership and 1 low ownership.

b) MIRAGE system

Participants were presented with live video footage of their hand in its actual location (delay less than 17ms; Newport et al., 2010) using the MIRAGE mediated reality system (University of Nottingham). In the current study participants viewed their hand under three conditions; (i) veridical condition – with no manipulation (ii) pixelated condition in which the appearance of the hand was manipulated to create a static effect and a (iii) darkened condition – used as a control condition that matched the overall luminance level of the pixelated illusion condition (see Figure 6.1). During

the pixelated condition random pixels of the hand that changed/moved were replaced by black pixels, creating a static appearance on the hand. This was similar to the effect seen when no signal is transmitted to a television.

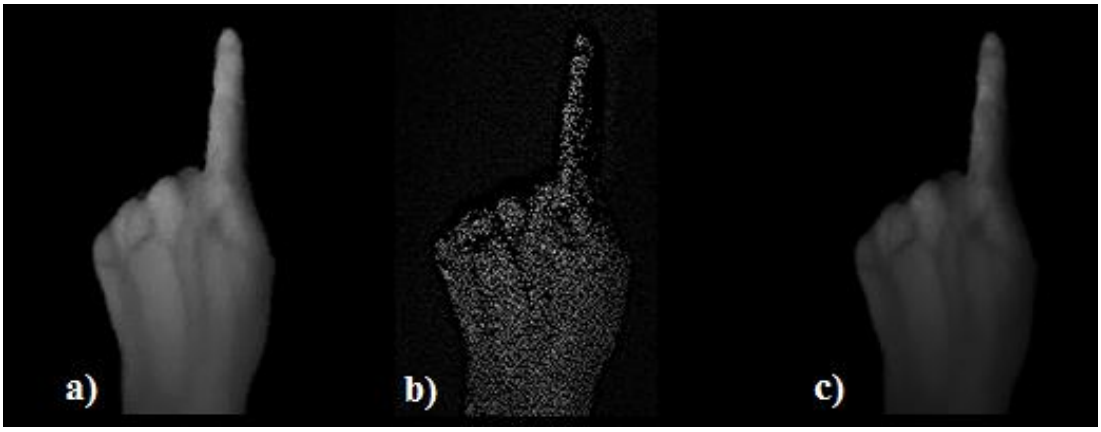


Figure 6.1: Visual illusions induced. (a) Veridical baseline (b) Static illusion (c) Darkened

c) Modified Somatic signal detection task (SSDT)

The stimulus array was identical to that described in Chapter 5; however no light emitting diode (LED) was embedded on to the polystyrene wedge. As described in Chapter 5, the electromagnetic solenoid stimulator (Dancer Design tactor; diameter 1.8mm) was affixed to the participant's left index finger with double sided adhesive tape. Tactile vibrations were delivered to the left index finger in line with evidence that the left (non-dominant) hand is more sensitive to vibrotactile stimuli than the right (dominant) hand (Rhodes & Schwartz, 1981). These vibrations were produced by sending amplified square wave sound files (100 Hz, 20ms) to the electromagnetic solenoid stimulator controlled by e-prime software (Psychology Software Tools Inc., Pittsburgh, PA, USA). An LED attached to the side of the stimulus array flashed for 250ms and signalled the start of each trial prompting participants to look at their left index finger. White noise was played via headphones throughout the experiment to prevent participants from hearing any experimentally informative sounds from the

electromagnetic solenoid stimulator. Participants made verbal “yes/no” responses about whether or not they felt the vibration.

Thresholding procedure: As described in Chapter 5, each participant’s individual tactile threshold was found using a staircase procedure (Cornsweet, 1962).

Experiment proper: Experiment proper consisted of three blocks, each corresponding to one of the three experimental conditions; veridical baseline, pixelated and darkened. Each condition consisted of a block of 60 trials, consisting of two trial types; vibration present and vibration absent (catch) trials. Each trial type was presented a total of 30 times in each block in a random order. The vibration was presented at the intensity previously determined during the thresholding procedure. Participants were asked to give “yes” or “no” about whether or not they felt the vibration in each trial.

6.2.3 Design and Procedure

A 3 x 2 repeated measures design in which condition (veridical-baseline, pixelated, darkened) and vibration (present, absent) were within-participant variables and participants’ “yes” and “no” response was the dependent variable was employed.

Participants received both written and verbal information and instructions about the task after which they were seated in front of the MIRAGE system and placed their hands inside it. A brief period of acclimatisation was given (approximately 30 seconds), during which time they were allowed to move their hands within MIRAGE system. This was followed by the acclimatisation questionnaire. The experimenter then placed participants’ left index finger on the stimulus array and their tactile threshold was found using the staircase procedure.

During experiment proper, participants first responded to statements that assessed ownership towards their un-manipulated hand during the baseline condition,

after which they completed the first (modified) SSDT block. This condition was used as a reference by which performance in other conditions were compared against and was therefore conducted first for all participants. This ensured that the baseline condition was not contaminated by any carryover effects from the static visual illusion condition as well as the darkened condition. Following this, participants were subjected to either the pixelated illusion condition or the darkened condition in a counter-balanced order. In each condition, participants first responded to ownership statements, after which the (modified) SSDT was conducted. At the end of each condition, the hand was brought back to its original appearance and a break of about 3 minutes was given before the next condition began. Participants were instructed to keep their hand still during the course of the experiment, and received no feedback.

6.3 Results

6.3.1Questionnaire responses

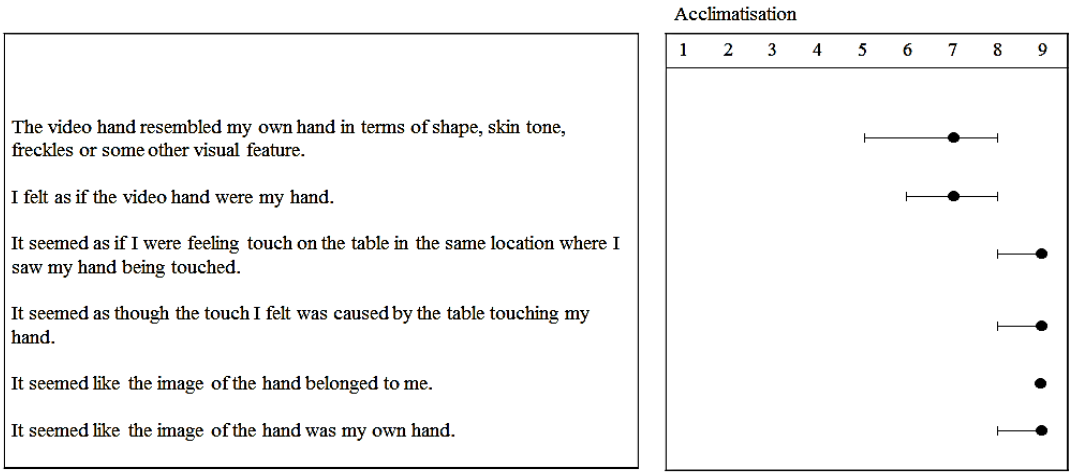
Questionnaire ratings were significantly negatively skewed (Shapiro Wilk statistic showed that $p<.05$) and remained so following transformation, consequently non-parametric analyses were used.

Acclimatisation questionnaire: A strong sense of ownership towards the video image of the hand was seen (see Figure 6.2a). Participants strongly agreed with statements such as *'It seemed like the image of the hand was my own'* (Median= 9) and *'It seemed like the image of the hand belonged to me'* (Median= 9).

Ownership questionnaires: Ratings to ownership questionnaires indicated a strong sense of ownership towards the hand during all three conditions (see Figure 6.2b). Ratings to the ownership statements *'I felt like I was watching myself'* and *'It seemed like the image of the hand were my own'* were averaged to obtain a mean

ownership rating. A Friedman's ANOVA revealed a significant difference in ownership between the three conditions (χ^2 (2, N=30) = 28.34, p<.001). Further Wilcoxon's tests examining these differences (at a Bonferroni corrected significance value of .0167) revealed ownership to be higher during the baseline condition (Median= 9) compared to the static condition (Median= 7.5; Z= -4.14, p<.001, r=.76). Ownership was also higher during the baseline condition (Median=9) compared to the darkened condition (Median= 7.5; Z= -4.11, p<.001, r=.75) however, no difference between the static and darkened conditions were found (Z= -.87, p=.39).

a) Acclimatisation



b) Ownership statements

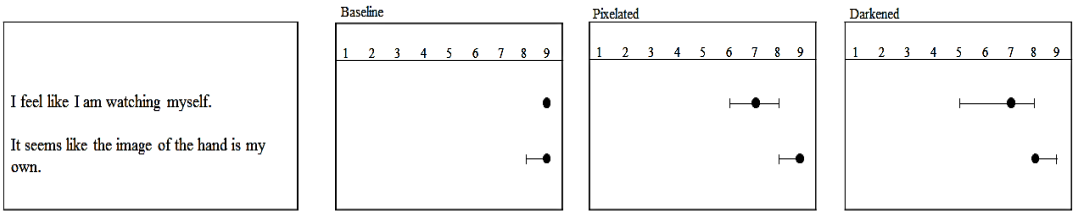


Figure 6.2: Medians and inter-quartile ranges for questionnaire ratings for (a) Acclimatisation and (b) ownership statements

6.3.2 SSDT parameters

As in the previous chapter participants' 'yes' and 'no' responses were classified as hits, misses, false-alarms and correct rejections. Hit rates and false-alarm rates were then calculated using the log linear correction (Snodgrass & Corwin 1988) and used to determine the signal detection theory test statistics *d'* and *c* (MacMillan & Creelman 1991). These provided estimates of participants' tactile sensitivity (*d'*) and response bias (*c*; willingness to report feeling the vibration regardless of whether or not one was present) respectively. Descriptive statistics for hit rates, false-alarm rates, sensitivity and response bias for all conditions are summarised in Table 6.1 below.

Table 6.1: Mean (± S.D) hit rates, false-alarm rates, sensitivity and response criterion across the three conditions.

Condition	Hit rates (%)	False-alarm rates (%)	*d'*	*c*
Baseline	52.24 (15.42)	9.40 (12.53)	1.65 (0.86)	0.77 (0.34)
Static	56.17 (19.15)	8.85 (8.31)	1.68 (0.73)	0.66 (0.37)
Darkened	57.21 (16.93)	9.51 (9.31)	1.70 (0.75)	0.64 (0.36)

A series of one-way repeated measures ANOVAs with condition (i.e. baseline, static, detached) as a within participant factor were conducted on hit rates, false-alarm rates, tactile sensitivity (*d'*) and response criterion (*c*). No main effect of illusion condition was seen for hit rates ($F_{(2,58)}$= 1.07, p =.35), false-alarm rates ($F_{(2,58)}$= . 09, p =.91), sensitivity ($F_{(2,58)}$= .081, p =.92) or response criterion ($F_{(2,58)}$= 1.60, p =.21).

6.3.3 Tendency of experiencing MUS and changes in somatic perception

This study also investigated whether individuals with higher and lower tendencies of experiencing MUS would perform differently across the conditions. The

relationship between mean ownership and SDQ-20 scores were initially examined. Pearson's product moment correlations revealed no significant association between SDQ-20 scores and ownership during the pixelated ($r(30)=-.055$, $p=.77$), darkened ($r(30)=-.12$, $p=.52$) or veridical ($r(30)=-.17$, $p=.37$) conditions.

Next, the association between SSDT parameters (false-alarms, sensitivity and response criterions) in each illusion condition and tendencies towards MUS were explored. Here again, no significant association between any of the parameters and tendencies towards MUS were seen (all $p>.05$).

6.4 Discussion

The primary aim of the current study was to investigate how increasing interoceptive awareness in the hand using a visual illusion altered somatic perception. The pixelated illusion was expected to create illusory somatic sensations in the absence of any real somatic input. Dysfunctional interoceptive awareness has previously been found to lead to misperceptions of somatic events and experiences (Mussgay et al., 1999; Ehlers et al., 2000); therefore this illusion was expected to increase false touch reports on the SSDT – reflecting distortions in normal somatic perception. Although the pixelated illusion has previously been found to enhance self-reported somatosensation in participants (McKenzie & Newport, 2015), the current findings revealed no differences in reported somatic experiences on the SSDT during the pixelated illusion condition, compared to veridical-baseline and darkened conditions. It is not clear why this might have been the case, however, this absence of any difference in somatic perception could be a result of a modality shift effect (MSE), in which processing of sensory information is impaired when there is a switch from one sensory modality to another (Spence, Nicholls & Driver, 2001). This is

thought to be a result of allocating attention to one source of sensory information at the expense of another. In line with this idea, Spence et al. (2001) demonstrated that attention to stimuli-location in one modality (*e.g.*, tactile) led to faster reaction times in subsequent stimuli of the same modality, compared to those of a different modality (*e.g.*, visual or auditory). Therefore, in the current study there might have been a cost in switching from the interoceptive modality to the exteroceptive modality. Although the MSE has been found to be rather short lived (Miles et al., 2011), in the current study, SSDT responses were made whilst being exposed to the illusion; this might have resulted in a need to continuously switch attention between sensory modalities when processing tactile information during the SSDT. In a recent study Mirams et al. (2012) found response criterions to be more liberal following a heartbeat perception task that aimed to increase interoceptive awareness. Unlike in the current study, that study investigated the effects of increased interoceptive sensations on somatic perception following the heart-beat perception task and not during the heartbeat perception task itself. This might have led to the above mentioned MSE in the current experiment, resulting in no observed differences in somatic perception. These results therefore highlight the importance of modality consistency and suggest that effects such as awareness of internal bodily sensations should perhaps be objectively investigated in similar modalities, for example counting number of internal pulse sensations felt. Alternatively, the null finding may also be due to any illusory somatic sensation inherent from the static illusion been considered task irrelevant and therefore overridden by somatic sensations that appeared more salient and task relevant, such as the tactile vibration of the SSDT. Indeed, there is evidence for the suppression of visual processing of stimuli when they are task irrelevant and vice-

versa when it is task relevant (Gazzaley, Cooney, McEvoy, Knight & D'Esposito, 2005).

Furthermore, while individuals with increased tendencies towards MUS were expected to be more susceptible to the illusion and report more false-alarms, the absence of such an effect may again be explained through the MSE. The cost in switching from the interoceptive modality to the exteroceptive modality may have been higher for the individuals with increased tendencies towards MUS. In line with this, patients with schizophrenia (who also display distorted somatic awareness) have been found to be more strongly impaired when responding to cue-target stimuli of different modalities (Ferstl, Hanewinkel & Krag, 1994; Maier et al., 1994). Alternatively, while the illusion was previously found to exert a top-down influence on somatosensation (McKenzie & Newport, 2015), it is possible that the large amount of visual noise inherent during the pixelated illusion, in fact contradicted prior-knowledge about the hand and diminished the effect of false-alarms on the SSDT perhaps by directing attention away from the hand as all sensory information from the hand may have been considered unreliable. Similar findings were made by Miles et al., (2011). They found high SDQ scorers to have reduced embodiment over the fake hand during the RHI as this contradicted top-down knowledge relating to their body (such as beliefs, knowledge and expectations). This disproportionate reliance on top-down knowledge as opposed bottom-up sensory information, is also in line with previous SSDT studies that have found high symptom reporters (as measured by the SDQ-20) to report more false-touch reports in the presence of a task irrelevant light (Brown et al., 2010). Future studies examining illusion susceptibility in MUS populations should therefore be cautious of the extent to which top-down knowledge of the body is distorted by the illusion.

In conclusion, the current findings provided no evidence for alterations in somatosensation as a result of the visual illusions perhaps due a MSE or reduced salience of the illusion itself. Surprisingly, increased tendencies towards MUS were also not associated with increased false-alarms, suggesting that such individuals may have either suffered a greater MSE or merely that the strong illusory effects directed attention away from the hand given its extreme unusual appearance. Nevertheless, the current results are theoretically relevant as they highlight key factors to be considered at least in the investigation of interoceptive somatic sensations. Furthermore, given the limited treatment options available for MUS (Brown, 2007), further research examining the nature of body representation distortions experienced by such patients would lead to the development of effective intervention programs.

CHAPTER 7

GENERAL DISCUSSION

7.1 Background to Thesis

A sense of ownership towards the body and its parts is required for maintaining meaningful somatic experiences and interacting successfully with the external environment (*i.e.*, with objects and people around us; Giummarra, Gibson, Georgiou-Karistianis & Bradshaw, 2008). Somatic experiences are multisensory by nature and are constructed through the successful integration of sensory inputs including; visual, tactile, vestibular, proprioceptive, and interoceptive information in brain areas including the premotor and parietal cortices. Although somatic experiences may intuitively seem to be stable and always reflect reality, numerous clinical conditions and experimentally-induced somatic illusions have shown that the experiences of the body is not solely determined by stored mental representations but can be updated following sensory manipulations or damage to cortical regions involved in sensory integration (*e.g.*, Botvinick & Cohen, 1998; Deary, Chalder, & Sharpe, 2007; Vallar & Ronchi, 2009). Experimentally-induced somatic illusions suggest that altered somatic states are indeed characteristic features of healthy body representations. Such illusions create distorted body experiences under laboratory conditions and provide a means of investigating the mechanisms underlying the development of these experiences.

Somatic illusions have provided evidence for ownership towards additional body parts (Botvinick & Cohen, 1998; Newport, Pearce & Preston, 2010) as well as manipulated body parts (Bruno & Bertamini, 2010; Banakou, Groten & Slater, 2013). While some studies have suggested ownership of both enlarged and shrunken body

parts (Bruno & Bertamini, 2010; Banakou et al., 2013; Linkenauger, Leyrer, Bülthoff & Mohler, 2013) indicating altered mental representations of the body, others have failed to demonstrate ownership towards shrunken body parts (Pavani & Zampini, 2007; Haggard & Jundi, 2009; Marino, Stucchi, Nava, Haggard & Maravita, 2010) perhaps indicating disownership of such representations (Ramachandran & Ramachandran, 2007). As a result, the precise mechanisms underlying ownership towards altered somatic representations are not clear and thus require closer investigation. Manipulations of body shape and size have also been found to alter somatic sensations on the skin (Kennett, Taylor-Clarke & Haggard, 2001; de Vignemont, Ehrsson & Haggard, 2005) and even temporary relief from chronic and acute pain (Moseley, Parsons, & Spence, 2008; Mancini, Longo, Kammers & Haggard, 2011; Preston & Newport, 2011). Here again, it is unclear whether the observed changes in response patterns under various illusion conditions are driven by response bias or changes in sensitivity. Therefore, the primary aim of the research within this thesis was to investigate the mechanisms responsible for altered somatic experiences following exposure to enlarged and shrunken body parts and to examine the processes by which illusory manipulations of the body altered somatosensation.

Tendencies towards experiencing somatic distortions have often been reported to alter susceptibility and responsiveness to somatic illusions (Burrack & Brugger, 2005; Brown, Brunt, Poliakoff & Lloyd, 2010b; Miles, Poliakoff & Brown, 2011). This thesis, therefore, also examined individual differences in such processes using questionnaire measures. More specifically; (i) the influence of heightened somatic awareness/sensitivity on illusion susceptibility and (ii) individual differences in response patterns to a type of somatic misperception – medically unexplained symptoms (MUS; Deary et al., 2007) were examined in relation to proposed clinical

models. In addition to providing evidence for the mechanisms underlying illusory alterations of body size and the mechanisms by which manipulated body representations alter somatosensation, the findings also shed light on various other factors – such as visual attention and interoceptive awareness – that contribute to distorted somatic experiences. A summary of each experimental chapter will be discussed below, followed by the theoretical and practical implications of the findings.

7.2 Summary of Findings

7.2.1 Chapter 3: Examining the degree of subjective susceptibility to multisensory illusions of body shape and size

a) Summary

While there is evidence suggesting that a majority of participants (93%) across all ages are susceptible to visuo-proprioceptive illusions that create a feeling that the index finger was stretched (Newport et al., 2015), participants' self-rated illusion strength experience and ownership over these distorted representations of the finger remains unexamined. The pilot study reported in Chapter 3 examined illusion strength and ownership over a series of illusions generated via the MIRAGE mediated reality system; stretched finger, shrunken finger, stretched hand and shrunken hand. The experiment also included a veridical condition in which no illusion was present.

Results indicated that participants strongly felt their finger/hand to be stretched and shrunken following the multisensory illusions. Interestingly, despite these distortions, ownership was still claimed over the altered body parts. No significant overestimations or underestimations of the finger and hand were present during the veridical condition.

b) Interpretation

The strong illusion strength ratings following each illusion provided evidence for the dynamic flexibility of the body representation. Altering the perceived body representation for a brief period of time therefore changes individuals' perceptions of the body representation.

7.2.2 Chapter 4: Altered body representations following a brief exposure to multisensory distortions of the hand

a) Summary

Traditional studies of ownership and embodiment have generally been limited to static rubber hands or video images (of participants' own hand) that permitted little or no movement (Pavani & Zampini, 2007; Haggard & Jundi, 2009). These studies have demonstrated a failure to acknowledge shrunken body parts into the body representation, however, more recent studies have demonstrated ownership and embodiment towards both larger and smaller body parts in virtual environments following congruent visuo-tactile feedback (Slater, Spanlang, Sanchez-Vives & Blanke, 2010; Linkenauger, Witt & Proffitt, 2011; van der Hoort, Guterstam & Ehrsson, 2011; Linkenauger et al., 2013). Mixed evidence in this regard calls for closer inspection of the conditions that allows ownership under certain conditions and not others. In addition to being criticised for a lack of realism (Linkenauger et al., 2013) the majority of virtual reality studies have only provided evidence for ownership towards distorted body parts via indirect scaling techniques. Using the MIRAGE mediated reality system (in which the visual representation of own body size was altered) this chapter investigated the mechanisms responsible for altered body representations following illusory manipulations of perceived body shape and

size. Given that large individual differences are reported in responsiveness to various illusions (Burrack & Brugger, 2005; Miles et al., 2011) and that illusion therapy has been useful in correcting abnormal body representations in clinical populations (*e.g.*, chronic pain, eating disorders; Moseley et al., 2008; Preston & Newport, 2011; Ferrer-García & Gutiérrez-Maldonado, 2012; Aimé, Cotton, Guitard & Bouchard, 2012) the chapter also examined individual differences in illusion susceptibility using the Somatosensory Amplification Scale (SSAS; Barsky, Wyshak & Klerman, 1990) – a proxy measure of tendencies towards aberrant body experiences (Barsky et al., 1999; Gregory, Manring & Berry, 2000; Gregory, Manring & Wade, 2005; Sagardoy et al., 2015).

Questionnaire responses across all three experiments indicated that participants strongly felt each illusory manipulation and that ownership was retained over the altered body parts – even when they were shrunken. An online task indicated that participants' preferred body-size following size altering illusions was influenced by the nature of that illusion, with stretched and shrunken body parts being judged as 'normal', or veridical, following illusory stretching and shrinking respectively. While it could be argued that these effects were merely a result of participants responding to the direction of each manipulation following the illusions, similar response patterns were demonstrated even following a manipulation aimed at controlling and ruling out such confounds. Using a divider, an offline measure of perceived real body representation was also obtained prior to the illusory manipulations and post-illusion. While no overestimations in perceived body size was seen following the stretched finger illusion, the shrunken finger illusion led to significant underestimations in perceived body size. Finally, SSAS scores were found to be positively associated with

self-reported illusion strength scores when the finger appeared to be stretched; however, this effect was only significant for females.

b) Interpretation

The results indicated that participants' perceived veridical body representation was updated following the illusions. The findings also revealed ownership towards both stretched and shrunken somatic representations, and contradict past literature indicating ownership to only enlarged body parts (Pavani & Zampini, 2007; Haggard & Jundi, 2009) as shrunken body parts were also judged to be of veridical size following illusory shrinking. These updated body representations provide evidence for altered mental representations of the body. The findings also demonstrated the first known direct evidence for updated body representations following size altering illusions and fit with a broader body of literature indicating that the body representation can be instantly updated following dynamic and real-time visual, tactile and proprioceptive feedback (Slater et al., 2010; Linkenauger et al., 2011; van der Hoort et al., 2011; Linkenauger et al., 2013). We have also demonstrated the first documented link between self-reported SSAS scores and subjective illusion susceptibility. Although the association was only found to be significant for females during the stretched illusion, this still suggests that heightening somatic sensitivity/awareness maybe linked to susceptibility to somatic illusions (for females at least). Indeed, females have been found to provide more accurate reports of their somatic sensations/awareness (Pennebaker & Roberts, 1992; Pennebaker, 1995) which may have resulted in the observed link between SSAS scores and illusion susceptibility for females only. Given that disrupted somatic awareness increases the risk of developing pathologies of altered body representations including chronic pain states (Barsky et al., 1999; Gregory et al., 2000; Gregory et al., 2005) and eating

disorders (Sagardoy et al., 2015); perhaps this finding may suggest that SSAS scores are an indicator of illusion susceptibility, and as a result can be used to identify individuals (with body representation disorders) most likely to benefit from illusion therapy.

7.2.3 Chapter 5: Investigating the effects of multisensory distortions of the hand on near threshold tactile perception

a) Summary

Manipulating perceived body shape and size has been found to alter somatosensation, assessed via tactile detection tasks. While most previous studies have been limited to magnified or enlarged body parts (Kennett et al., 2001) others have failed to find changes in response patterns (to tactile stimuli) following shrunken body parts (de Vignemont et al., 2005). Furthermore, the precise mechanisms underlying altered response patterns following manipulations of body size are also unclear. Are such changes driven by a response bias, indicating an increased tendency to say 'yes', or could such manipulations alter perceptual sensitivity (*i.e.*, the ability to discern stimulus present from stimulus absent trials)? Furthermore, while there is at least some evidence for altered somatosensation following manipulations of body shape and size (Kennett et al., 2001; de Vignemont et al., 2005), no study has yet examined tactile perception following perceived discontinuity of a body part. Chapter 5, therefore, examined the mechanisms underlying altered tactile perception following manipulations of body size as well as following perceived discontinuity of a body part. The Somatic Signal Detection Task (SSDT; Lloyd, Mason, Brown & Poliakoff, 2008); a cross-modal tactile detection task that requires detection of near threshold tactile stimuli presented alone or in conjunction with a task irrelevant visual stimulus was used. Using signal detection analyses (Macmillan & Creelman, 1991) the task

provides a means of establishing whether changes in tactile detection under different experimental conditions are driven by changes in response bias or sensitivity. Therefore, this chapter examined how illusory manipulations generated via the MIRAGE system altered tactile perception on the SSDT. These somatic illusions induced top-down alterations to the perceived body representation via synchronous bottom-up sensory processes. In line with evidence reporting tendencies towards MUS to be negatively associated with susceptibility to illusions induced under similar mechanisms (*e.g.,* RHI- Miles et al., 2011), the link between subjective susceptibility to the current illusions and subjective tendencies towards MUS were examined with the aim of extending previous findings to MIRAGE generated illusions. Furthermore, false-touch reports on the SSDT (false-alarms) are thought to closely mirror somatic distortions experienced by individuals with MUS (Brown et al., 2010). This Chapter, therefore, also examined the link between false-alarm rates and tendencies towards MUS using the SDQ-20 (a proxy measure of MUS; Nijenhuis, Spinhoven, Van Dyck, Van der Hart & Vanderlinden, 1996; Maaranen et al., 2005) as well as how strongly false-alarm rates predicted subjective tendencies towards MUS.

Similar behavioural response patterns were observed following illusory enlargement of body size at the site of stimulation (*i.e.,* the finger) and away from the site of stimulation (*i.e.,* the hand). Interestingly an improvement in tactile detection (hit rates) was also observed following shrinking of the finger (at the site of stimulation) as well as following shrinking of the hand (away from site of stimulation) compared to veridical conditions. Although similar behavioural outcomes following illusory alterations of the finger and hand were observed, different mechanisms were found to underlie these improvements. While liberal response criterions and better tactile sensitivity was responsible for improved hit rates following illusory stretching

and shrinking of the finger respectively, both liberal response criterions and improved tactile sensitivity drove the increase in hit rates when the hand was stretched and shrunken. The detached finger condition was found to reduce false-alarm rates compared to the veridical-baseline condition. This effect was found to be associated with more stringent response criterions indicating that participants said ‘no’ more often when the finger appeared to be detached. The task-irrelevant light significantly increased reports of feeling the vibration, regardless of whether or not one was present; leading to increases in both hit rates and false-alarm rates.

No association between subjective tendencies towards MUS and illusion susceptibility was seen; however, SDQ-20 scores were significantly, and positively, correlated with overall false-alarm rates, and negatively associated with tactile sensitivity. Regression analyses revealed false-alarm rates to significantly improve the predictive power of the regression equation and to be the most significant predictor MUS scores.

b) Interpretation

While the precise mechanisms underlying altered tactile perception following illusory manipulations of perceived body size have been unclear in previous research, it was found that in terms of tactile detection at least, similar response outcomes are governed by separate underlying processes. Illusory finger elongation may have altered corresponding somatosensory cortical regions (Schaefer et al., 2007). These regions have dense connections with parietal areas containing visuo-tactile bimodal neurons (Zhou & Fuster, 1997; Schaefer, Heinze & Rotte, 2005b) and may have modulated activity of the bimodal neurons leading to improved tactile perception following illusory finger stretching. Given that visible somatic information (of the stimulated body part) was lower following illusory shrinking, the shrunken finger

illusion may have resulted in a sensory shift to the tactile modality resulting in improved sensitivity. Indeed, it is suggested that in instances in which visual information is unreliable, there is a sensory shift to a different modality (Ernst & Banks, 2002) which in this case was the tactile modality.

Tactile perception in the SSDT is often confused with ambiguous interoceptive sensations such as feeling the pulse (caused by blood flow). Under conditions of non-informative vision of the hand, the sensation of these pulses leads to tactile misperceptions or false-alarms (Mirams, Poliakoffm Brown & Lloyd, 2010). Illusory stretching and shrinking at the site of stimulation may have overridden these effects via the above discussed mechanisms. Alternatively, illusory stretching and shrinking of the hand may have attracted more attention to the hand – thus directing attention away from the site of stimulation and reduced the influence of distracting interoceptive sensations. This would have led to improved tactile detectability under similar underlying mechanisms – improved sensitivity and liberal response criterions. Similar mechanisms were believed to operate during the detached finger condition. During this condition, tactile attention may have only been directed to a part of the finger perhaps the tip rather than to the whole finger more generally, thus reducing the influence interoceptive sensations or 'noise' especially in signal absent trials. The different behavioural outcomes following altered hand size and the detached finger condition highlights the influence of an overall reduction in 'noise' in the stimulated body part as opposed to 'noise' arising only from a part of the stimulated body part which in this case was the tip of the finger. In line with previous SSDT studies, inclusion of the task-irrelevant light increased positive reports of feeling the vibration regardless of whether or not one was present (Johnson, Burton & Ro, 2006; Lloyd et al. 2008; McKenzie, Poliakoff, Brown & Lloyd, 2010; Mirams et al. 2010). The

absence of an association between SDQ-20 scores and illusion strength ratings generated via the MIRAGE system suggests that in addition to the mechanisms eliciting the illusion, the nature of the illusion may also be crucial in reflecting individual differences in susceptibility particularly for MUS. While tendencies towards MUS have been found to be negatively associated with susceptibility to somatic illusions such as the RHI (Miles et al., 2011) which involves embodiment of an artificial limb following discrepant sensory input, the illusions employed in Chapter 5 (Experiment 3) only manipulated perception of the finger in terms of its appearance. Nevertheless, overall false-alarms rates and sensitivity were correlated with SDQ-20 scores. This finding is in line with Rief and Barsky's (2005) proposed model of MUS which suggests MUS to be associated with a filtering deficit characterised by an inability to filter out noise. By this view MUS stem from disrupted perceptual processes.

7.2.4 Chapter 6: Does visually evoked somatosensation interfere with somatic perception?

a) Summary

Chapter 6 further examined the effects of an altered body representation on tactile perception, this time using a purely visual illusion. The illusion created a moving pixelated appearance on the skin which was previously found to give rise interoceptive somatic sensations in the absence of any real somatosensory input (McKenzie & Newport, 2015). In this way, the illusion exerted a top-down influence on somatosensation. Therefore, in comparison to previous studies that have examined interoceptive influences via physical methods, that increased heart-beat perceptions or the feeling of internal pulse sensations, Chapter 6 examined whether illusory interoceptive sensations would interfere with, and alter the perception of near

threshold tactile sensations on a (modified) SSDT. Furthermore, given the disproportionate top-down reliance in those with propensities towards MUS (Brown, 2004), the illusion also provided a means of examining the link between tendencies towards MUS (assessed using the SDQ-20) and susceptibility to illusions that are purely top-down driven as opposed to illusions such as the RHI (Miles et al., 2011).

No overall differences in hit rates or false-alarm rates were seen between the illusion condition and the two control conditions. The pixelated appearance also did not alter response patterns on the SSDT between individuals with increased and decreased propensities towards MUS.

b) Interpretation

Whilst one may argue that the altered response patterns following the size altering illusions in Chapter 5 could simply be explained in relation to novelty effects as a result of the unusual appearance of the hand/finger, the null result in Chapter 6 suggests that the findings of Chapter 5 cannot be explained solely in terms of an unusual appearance of the body per se. The absence of any differences in tactile perception across the three conditions could, however be explained with regard to the modality shift effect (MSE) which suggests a cost in shifting attention from one sensory modality to another (Spence, Nicholls & Driver, 2001). Therefore, there might have been a constant cost in shifting attention from the interoceptive modality to the exteroceptive tactile modality (during the SSDT) especially during the pixelated illusion condition. Alternatively, as discussed in Chapter 6, tactile detection during the SSDT may have appeared to be more task-relevant and salient to participants resulting in any illusory sensations generated by the pixelated illusion appearing task-irrelevant (Gazzaley, Cooney, McEvoy, Knight & D'Esposito, 2005) thus leading to an overall null finding. It should also be noted that while the illusory manipulations employed in

Chapter 5 demonstrated how a combination of bottom-up sensory processes altered body shape and size, Chapter 6 involved purely visual manipulations that altered the appearance of the body and created somatic sensations in the absence of any real tactile input. Therefore, the absence of any overall difference in tactile perception across the visual illusions in Chapter 6 may perhaps suggest that the nature of the illusory manipulations may have different effects on near-threshold tactile perception.

While according to the findings of McKenzie and Newport (2015) and recent theories of MUS (Brown, 2004), higher tendencies towards MUS were expected be associated with greater illusory somatic sensations leading to elevated false-alarm rates on the SSDT. Self-reported tendencies towards MUS were not associated with SSDT responses across the conditions. This null effect could be a result of individuals with tendencies towards MUS suffering a stronger MSE – perhaps the suggested increased somatic preoccupation in such individuals may have led to a greater cost in shifting between different sensory modalities. While this suggestion warrants further study, it should be noted that strongMSEs are also reported in other patient populations in which distorted beliefs of the body representation are commonly reported (*e.g.*, schizophrenia - Ferstl, Hanewinkel & Krag, 1994; Maier et al., 1994). Furthermore, as discussed in Chapter 6, the increased visual noise inherent from the illusion during the pixelated condition may have diminished its influence on external somatosensation or the SSDT responses, possibly due to attention been directed away from the hand in general, as incoming visual information from the hand appeared to be unreliable. Such avoidance behaviours have indeed been reported in individuals prone to somatic amplification, when confronted with threatening body representations (Brown, Poliakoff & Kirkman, 2007). Therefore, given that the nature of the illusion is crucial in determining individual differences in susceptibility across

various clinical/subclinical populations (particularly MUS), future studies should be cautious of the extent to which prior-knowledge of the body is altered. Therefore, employing manipulations in which beliefs about body perception are altered (*e.g.*, altering perception of the heartbeats) may perhaps be more useful in examining individual differences MUS populations.

7.3 Theoretical Implications

7.3.1 Perceived body shape and size

Chapters 3 and 4 provided subjective and objective evidence for altered body representations following illusory manipulations of body shape and size. In Chapter 4, the fact that perceived body representation was influenced by the nature and direction of each illusion rules out explanations that could be based merely on novelty and expectations. Further strengthening this argument, the offline task that estimated perceived body size using a non-body standard provided evidence for an updated representation following the shrunken illusion. If the observed effects merely reflected novelty/expectation effects or simply even a bias to say “stop” early (during the online task) altered response patterns would not be observed during the offline task. Offline body representations are said to provide stable estimates of what the body usually feels like (Carruthers, 2008). One may argue that given this definition, no overestimation or underestimation of perceived body size should be expected during the offline body size estimation task. It should, however, be noted that the offline task revealed no significant difference between perceived initial body size (prior to the illusions) and following illusory stretching. This suggests that access to stored (offline) representations of the body would have been much stronger following illusory stretching (compared to shrinking). This could perhaps be because the long-

term mental representation of the body that progresses through development contains information relating to the shape and size of the body until adult size is reached (O'Shaughnessy, 1995; Melzack, Israel, Lacroix & Schultz, 1997) and may not be further altered following exposure to brief periods of illusory manipulation. Therefore, while illusory alterations of body shape and size may update current (online) body representations irrespective of the direction of the manipulation, stored (offline) representations may prevent overestimations of perceived body size. Conversely, using an offline measure, Mancini et al. (2011) found evidence for updated body representations following both enlarged and shrunken body sizes; however, that study included no estimation of perceived body size in the absence of, or prior to, the illusions. While body shape and size was typically found to be updated approximately 80-90 seconds following the illusion in the current studies, the exact time-course over which perceived body shape and size can be altered warrants further study. Perhaps longer exposure to the stretched illusion in particular may update both online and offline body representations.

The altered body representations that were judged as veridical body size provide direct evidence for an altered mental representation of the body independent of sensory alterations, including tactile perception (Kennett et al., 2001; de Vignemont et al., 2005), haptic judgements (Bruno & Bertamini, 2010) and scaling techniques (Linkenauger et al., 2013; Banakou et al., 2013). While anecdotal reports have suggested that the body representation resists shrunken body parts (Ramachandran & Ramachandran, 2007), Chapter 4 demonstrated that providing manipulated video footage of participants' own hands in real time altered real body size such that the direction of the size altering illusion (stretched/shrunken) formed the basis of the updated body representation. Although body shape and size could be

altered via traditional techniques that utilised magnifying and minifying lenses, there are limits to manipulating the properties and dimensions of body parts via such methods. Furthermore, although virtual reality studies permit real-time alterations of seen and perceived body size as well as motion tracking, the generalisability of studies conducted in virtual environments to real environments could be called to question due to reduced realism. In virtual environments participants' body movements are mapped onto self-representing avatars, therefore the body/body part seen in the virtual environment may not match participants' physical body, resulting in them being influenced by information in the virtual environment which would not normally be influential in real environments (Linkenauger et al., 2013). In contrast to traditional techniques and virtual reality technology, the MIRAGE system allowed dynamic and realistic modulation of perceived own body size in real time thereby providing congruent visual, tactile and proprioceptive feedback during the illusions. The congruent sensory feedback would have created realistic sensations that the body representation was altered leading to ownership towards the manipulated representations of the body. Therefore when asked to indicate perceived real body size following the illusions, longer and shorter representations of the body were judged as veridical length. Indeed, perceptual and motor synchrony has been found to be sufficient to give ownership towards such altered somatic representations (Slater, Perez-Marcos, Ehrsson & Sanchez-Vives, 2009; Sanchez-Vives, Spanlang, Frisoli, Bergamasco & Slater, 2010). Together with previous findings (Botvinick & Cohen, 1998; Schaefer, Flor, Heinze & Rotte, 2006a), Chapters 3 and 4 indicated that the body representation is not fixed and can be altered via sensory manipulations of vision, touch and proprioception. Therefore, while integrated multisensory mechanisms may shape somatic experiences by providing information of one's

internal and external environment, such processes could also distort somatic experiences. Somatic perception is therefore a dynamic process that is continuously updated via sensory feedback. Although this transitory nature of the body representation may appear to have detrimental effects (*e.g.,* somatoparaphrenia and BIID) on somatic experiences, it also offers some survival value, making it possible to adapt to physical changes the body goes through with time (*e.g.,* old age, physical injuries), incorporate tools to attain goals (Iriki, Tanaka & Iwamura, 1996) and also embody prostheses following amputation (Melzack, 1990).

As mentioned earlier, the illusions updated perceptions of the body representation. Altered body representations have previously been found to also alter corresponding cortical regions, namely the primary somatosensory cortex (S1; Schaefer et al., 2007). This region receives direct somatotopic input from higher order parietal regions which have been found to code and respond to changes in hand/arm position (Holmes & Spence, 2004). The parietal regions contain complex neurons that discharge when the hand or arm is touched (Taoka, Toda & Iwamura, 1998) and/or moved (Lloyd, Shore, Spence & Calvert, 2003), therefore, although speculative at the time, the recalibration of the felt position of the hand (during the current illusions) would have altered activity of these cells which in turn may have modulated topography of S1 (Schaefer et al., 2007). The tactile funnelling illusion (in which simultaneous touches applied to many regions of the skin is perceived as a single tactile sensation arising from the centre of that area) has been found to lead to focal cortical activation in S1 in the perceived location, rather than the actual physical location of stimulation in squirrel monkeys thus extending these findings to animal studies (Zhou & Fuster, 1997; 2000) and suggesting that S1 dynamically adjusts to different situational requirements (Chen, Friedman & Roe, 2003). Furthermore,

magnetoencephalographic responses revealed varied activation patterns within S1 when participants were asked to detect the direction of motion of tactile stimulation applied to the hand, as opposed to when it was applied to the index finger. Cortical representation of the index finger was found to be more segregated from representations of the middle and ring fingers when participants were asked to detect direction of stimulation of the finger compared to the hand (Braun et al., 2002), thus highlighting attentional requirements in these tasks. Therefore while cortical sensory regions may aim to maintain accurate body representations, it can be extended beyond previous experiences to produce illusory perceptions of body position, which are not constrained by the anatomical range of the joints and muscles (Jones, 1988; Lackner, 1988).

7.3.2 Alterations to tactile sensation

While vision of the body has been found to alter tactile judgments (Kennett et al., 2001; Mirams et al., 2010), visually altering perceived bodily appearance has been found to further enhance this effect (Kennett et al., 2001; de Vignemont et al., 2005). The current studies provide evidence for tactile sensations to be altered via different underlying mechanisms following illusory alterations of body shape and size (Chapter 5). By this view, manipulating the body representation exerts a top-down effect on somatosensation.

Chapter 5 provided evidence for altered tactile perception on the SSDT independent of the effect of the light. Non-informative vision of a stimulated body part has indeed been found to alter somatosensation by increasing activity of bimodal neurons that respond to both vision and touch. Single cell recording studies in animals have found cells that respond to both visual and tactile stimuli in the premotor and parietal regions (Rizzolatti, Scandolara, Matelli & Gentilucci, 1981; Graziano &

Gross1994; Gross, 1993) while Lloyd et al. (2003) found these regions to be involved in visuo-tactile integration in humans. Activity of premotor and parietal cells depend on the availability of vision of the stimulated body part as reduced activation has been observed in the absence of vision of the stimulated body part (Mackay & Crammond, 1987; Graziano, Yap & Gross, 1994). As a result, body size elongation and shrinking would be expected to have different effects on subsequent tactile processing.

In addition to the modulatory effects of vision on a seen body part, tactile perception could also be altered by presenting a visual stimulus such as a light in close proximity. The SSDT (Lloyd et al., 2008) requires detection of a target tactile stimulus delivered in the presence or absence of a task irrelevant visual stimulus that is spatially and temporarily congruent. Improved detection of tactile target stimuli that are accompanied by the light reflects an enhancement effect elicited by the visual stimulus. Signal detection analyses have revealed these enhancement effects to almost always be associated with a strong change in response bias (Lovelace, Stein & Wallace, 2003; Johnson et al., 2003; Lloyd et al., 2008) suggesting a robust tendency to report feeling a sensory event that is paired with vision and moderate improvements in sensitivity (Johnson et al., 2003; McKenzie et al., 2010). The bias to positively report feeling the target stimulus in the presence of the task-irrelevant visual stimulus is therefore assumed to be a consequence of correlated multisensory experiences in one's lifetime (Johnson et al., 2006). By this view, visuo-tactile pairing on the SSDT is reliant on a lifelong association between visual and tactile stimuli in close proximity. Changes in hit and false-alarm rates in the presence of the visual stimulus on the SSDT therefore suggests that participants often rely on the visual stimulus when making judgments about the degraded tactile stimulus (Johnson et al., 2006). In this way the task-irrelevant visual stimulus may aid in resolving ambiguity

of the tactile stimulus by perhaps increasing attention to the hand (Spence, Nicholls, Gillespie & Driver, 1998) or creating a tactile representation in memory (Brown, 2004; Lloyd et al., 2008).

It could be argued that the absence of an interaction between the illusion condition and light in Chapter 5 (sections 5.6 and 5.10) was a result of the simultaneously presented visual and tactile information on the SSDT. Indeed, in many previous visuo-tactile integration tasks such as cross-modal congruency tasks, the cross-modal congruency effect has been found to be largest when visual stimuli preceded tactile stimuli by approximately 30ms (Spence, Pavani, Maravita & Holmes, 2004). Simultaneously presented multisensory events have, however been demonstrated to be better integrated (Vatakis & Spence, 2008) into a unified multisensory percept according to the unity assumption (which suggests that participants may perceive multisensory events as unified due to the low-level congruence of two sensory events; Vatakis, Ghazanfar & Spence, 2008). Therefore, in the case of the SSDT the simultaneous task irrelevant visual stimulus and the tactile stimulus would be bound together when presented in a single trial.

7.3.3 Individual differences in response patterns

While increased susceptibilities to somatic illusions (Burrack & Brugger, 2005) and optical illusions such as the Ponzo iIlusion (Miller, 1997) have been previously reported in females, the novel finding in Chapter 4 was that gender differences in susceptibility to illusory changes in body shape and size are in fact linked to self-reported tendencies towards amplifying somatic sensations or self-reported somatic awareness. The simplest explanation for such a finding could be that females provided more precise accounts of their somatic sensation (Pennebaker & Roberts, 1992; Pennebaker, 1995), thus making their SSAS scores more accurate

representations of tendencies towards somatic distortions. Additionally, there is also evidence suggesting that females more commonly acknowledge experiencing distorted bodily states compared to males (Barsky, Peekna, & Borus, 2001). As a result, more chronic pain states and other distorted bodily experiences, including eating disorders (Lewinsohn, Seeley, Moerk & Striegel-Moore, 2002; Rustøen et al., 2004; Striegel-Moore et al., 2009), are more frequently reported in females. Although one might argue that this result may indicate that females with high SSAS scores are merely more suggestible compared to low scoring females on the SSAS, it should be noted that thus far there have been no accounts of any known associations between somatosensory amplification and suggestibility.

The observed correlation between false-alarm rates and sensitivity with SDQ-20 scores in the presence and absence of the light (in Chapter 5) suggest that similar mechanisms may be operating in both cases. The observed negative correlation between self-reported unexplained symptoms and sensitivity could be regarded as evidence for dysfunctional perceptual processes in MUS. By this view MUS reflect an inability to filter out benign somatic events or in the case of the SSDT an inability to discern ‘signal’ from ‘noise’. In line with this, deficits in perceptual processing have been observed in MUS patients (Mailloux & Brener, 2002). While these findings provide evidence for the perceptual models (such as the signal filtering model; Rief & Barsky, 2005), it should be noted that there might be a certain degree of overlap between the signal filtering model (Rief & Barsky, 2005) and the integrative conceptual model proposed by Brown (2004). The filtering deficit may reduce reliability of somatic sensations (or in the case of the SSDT reliability of the incoming tactile sensation) resulting in the individual relying more heavily on top-down information such as beliefs and expectations when gathering somatic information

(Brown et al., 2012). This in turn could lead to overactive somatic representations in memory which could be activated by beliefs and prior knowledge, ultimately leading to MUS according Brown's (2004) model. In contrast to the change in false-alarm rates and perceptual sensitivity observed in Chapter 5, no changes in response patterns were seen in Chapter 6. Although this thesis does not provide evidence supporting a specific clinical model of MUS, such discrepant findings indicate that MUS may vary according to the clinical significance and the types of symptoms experienced (Brown et al., 2010). In line with this, normal perceptual abilities (Barsky, Brener, Coeytaux & Cleary, 1995; Aronsn, Barrett & Quigley, 2001) enhancements (Scholz & Sarnoch, 2001), as well as deficits (Mailloux, & Brener, 2002) in symptom processing have been observed in research relating to this area.

7.4 Practical Implications

Chronic pain states such as complex regional pain syndrome (CRPS) and osteoarthritis are associated with distorted body representations (Gilpin, Moseley, Stanton & Newport, 2014). Such individuals believe that their painful body part is usually larger or smaller than usual (Peltz, Seifert, Lanz, Muller & Maihofner, 2011). Multisensory somatic illusions that alter the perceived shape and size of these body parts have been found to modulate pain in patients with chronic pain (Moseley et al., 2008; Preston & Newport, 2011). While there has been some scepticism about the mechanism underlying illusion-induced pain relief (McCabe, 2011), the research findings in this thesis suggested that ownership was not lost following distortions of body shape and size, indicating that perhaps chronic pain relief may not be a result of disownership of the painful body part following illusory manipulations. Hence, these

findings suggest that such illusions may have therapeutic value in providing pain relief by correcting distorted body representations in clinical populations.

The SSAS was found to be a useful tool in identifying individuals who are most susceptible to illusory alterations of body shape and size. SSAS scores have been found to be a reliable indicator of chronic pain states with patients suffering from such conditions having higher scores on this scale (Barsky et al., 1999; Gregory et al., 2000; Gregory et al., 2005). The scale is also an indicator of eating disorder symptomology with such patients again scoring higher on this measure (Sagardoy et al., 2015). Given that illusion therapy has also proved therapeutically useful in treating patients with eating disorders (Riva, Bacchetta, Baruffi & Molinari, 2002; Riva, Bacchetta, Cesa, Conti & Molinari, 2003; for reviews see Ferrer-García et al., 2012; Aimé et al., 2012) we believe that the observed link between self-reported SSAS scores and illusion strength (during the stretched condition) might be useful in identifying (at least female) individuals who might be most amendable to body illusion therapies.

Furthermore, sensory discrimination training assessed via two-point discrimination tasks has been found to reduce pain in chronic pain patients (Moseley et al. 2008a, Moseley, Zalucki & Wiech, 2008b; Moseley & Wiech 2009; Stanton et al. 2013). Given that research in the current thesis has found alterations in tactile perception following illusory alterations of perceived body shape and size, perhaps pairing sensory discrimination training with MIRAGE size-altering illusions may provide insight into the nature of the distortions associated with chronic pain states such as CRPS and osteoarthritis.

7.5 Conclusions and Future Directions

This thesis investigated the mechanisms underlying somatic alterations of the body representation, the mechanisms by which these manipulated body representations altered somatosensation and individual differences in such processes. Perceived real body size was updated in the direction of the manipulation with longer and shorter body parts being judged as veridical (or normal) following stretched and shrunken multisensory illusions, thus suggesting that the mental representation of the body parts may have been updated following the illusions. In addition to updating perception of the body representation, these illusions were also found to differently alter near threshold tactile sensations. While manipulating body size at the site stimulation altered tactile perception via changes in response bias and sensitivity, both changes in response bias and sensitivity were found to alter tactile perception when body size manipulations were away from the site of stimulation suggesting similar underlying processes. The mechanisms driving altered somatic perceptions following distorted body representations may, therefore, depend upon the body regions to which the illusions are applied. Brief multisensory somatic illusions may, therefore, alter perception of the body, as well as external somatic sensations, thus highlighting the dynamic flexibility of the body representation. In addition to these primary findings, the thesis also demonstrated that tendencies towards increased somatic sensitivity in females (as measured by the somatosensory amplification scale) were associated with greater susceptibility to illusory resizing of a body part. In line with evidence suggesting somatic sensitivity to be associated with eating disorder symptomology (Sagardoy et al., 2015) as well as chronic pain (Barsky et al., 1999; Gregory et al., 2000; Gregory et al., 2005), this finding suggests that susceptibility to such size altering illusions may in fact be indicative of clinical/subclinical populations most

likely to benefit from illusion therapy. The illusions did not, however, reflect individual differences in tendencies towards MUS (as measured by the SDQ-20) thus indicating that the nature of an illusion may have differential effects across various populations. Tendencies towards MUS were, however, positively associated with overall false-alarm rates and negatively associated with tactile sensitivity, thus suggesting a deficit in interpreting sensory noise. The findings also provided the first known evidence that false-alarms on the SSDT were significant predictors of only MUS tendencies even when relevant covariates (SSAS and STAI-T) were accounted for.

While this thesis has provided further evidence of the mechanisms underlying misperceptions of the body representation and individual differences implicated in such misperceptions, this work could be further improved and refined.

Primarily, it would be interesting to examine how the size altering somatic illusions alter movement of the body, particularly, reaching and grasping movements. While the body image and body schema have been found to be differently sensitive to incorporating additional limbs into the body representation (Kammers, de Vignemont, Verhagen & Dijkerman, 2009; Newport et al., 2010), this investigation would provide particular insight into how we experience our body as well as the extent to which the body representation can be manipulated, thus facilitating further research into disorders involving altered body representations. Furthermore, an extension of this investigation may also provide insight into the processes underlying the sense of ownership and agency (*i.e.*, the experience that you are generating the movement of your body) and the conditions under which ownership and agency over the altered body representation is retained. Indeed, ownership and agency towards fake limbs have been found to be differently sensitive to systematic variation of anatomical

posture of the body and the mode of movement (active versus passive) suggesting a dissociation between the two (Kalckert & Ehrsson, 2012). This may have clinical implications in correcting distorted body representations (e.g., CRPS) in clinical populations as well as in prosthesis development.

The current body of work demonstrated that the body representation was updated following brief exposure to illusions; therefore, future experiments should perhaps examine the robustness of these illusory manipulations on perception of the body, and subsequent rate of decay. In relation to this, future experiments should also examine the time-course over which such illusory effects manifest and are maintained. This in particular would have useful implications in the development of targeted intervention programs for patient populations with distorted body representations including CRPS, osteoarthritis and eating disorders. There is also evidence suggesting that body shape and size provides a metric used to scale the apparent of size of the environment (van der Hoort et al., 2011; Linkenauger et al., 2013), in line with these studies it may be worth examining whether the altered effects to the body representation transfers from one body part to another. If we intuitively perceive our bodies to be roughly symmetrical, then, there should be a transfer of scale from one altered body part to another body part.

Lastly, it would be interesting to examine the neural correlates of altered body representations as well as the ownership. Previously S1 regions were found to be altered following manipulations to the body representation (Schaefer et al., 2007), while the premotor and parietal regions have been found to be involved with the sense of ownership (Ehrsson et al., 2004; Brozzoli, Gentile & Ehrsson, 2012). If similar mechanisms operate for size altering manipulations as other somatic alterations, in

which for example embodiment of an additional limb is present, then similar neural networks would be expected to be involved in the current illusions.

Therefore, the work of this thesis could be further extended to examine various other aspects of somatic perception following manipulated body representations (discussed above), nevertheless, our findings have provided direct evidence for the rapid updating of body representation following multisensory illusions and also extends previous literature by demonstrating the processes by which such representations alter somatic sensations. Links between individual predispositions towards certain clinical states and responses patterns were also observed, thus suggesting that these findings may be clinically relevant, and may point towards promising treatment avenues in the future.

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Appendix 1: Handedness

1.1 Edinburgh Handedness Inventory – 20 (Oldfield, 1971)

Please indicate your preferences in the use of hands in the following activities by putting + in the appropriate column. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, put ++. If in any case you are really indifferent put + in both columns.

Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets. Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

	Left Hand	Right Hand
1. Writing		
2. Drawing		
3. Throwing		
4. Scissors		
5. Comb		
6. Toothbrush		
7. Knife (without fork)		
8. Spoon		
9. Hammer		
10. Screwdriver		
11. Tennis Racket		
12. Knife (with fork)		
13. Cricket Bat (lower hand)		

14. Golf Club (lower hand)		
15. Using a Broom (upper hand)		
16. Rake (upper hand)		
17. Striking a Match (match)		
18. Opening box (lid)		
19. Dealing Cards (card being dealt)		
20. Threading needle (needle or thread according to which is moved)		
i. Which foot do you prefer to kick with?		
ii. Which eye do you use when using only one?		

Appendix 2: Illusion strength and ownership statements

2.1: Acclimatisation questionnaire

The video hand resembled my own real hand, in terms of shape, skin tone, freckles or some other visual feature.

I felt as if the video hand were my hand.

It seemed as if I were feeling touch of the table in the same location where I saw my hand being touched.

It seemed as though the touch I felt was caused by the table touching my hand.

It seemed like the image of the hand belonged to me.

It seemed like the image of the hand was my hand.

2.2: Veridical condition

a) I feel like my finger is longer than normal.
b) I feel like my finger is shorter than normal.
c) I feel like my hand is longer than normal.
d) I feel like my hand is shorter than normal.
e) I feel like I am watching myself.
f) I feel like I am watching someone else.
g) I feel like the finger and hand belong to me.
h) I feel like the finger and hand are under my control.

2.3 Stretched finger

a) I felt like my finger was really being stretched.
b) I felt like my finger was really being shrunken.
c) I feel like my finger is longer than normal.
d) I feel like my finger is shorter than normal.
e) I feel like I am watching myself.
f) I feel like I am watching someone else.
g) I feel like the finger belongs to me.
h) I feel like the finger is under my control.
i) I feel like my hand is longer than normal.
j) I feel like my hand is shorter than normal.

2.4 Shrunken finger

a) I felt like my finger was really being shrunken.
b) I felt like my finger was really being stretched.
c) I feel like my finger is shorter than normal.
d) I feel like my finger is longer than normal.
e) I feel like I am watching myself.
f) I feel like I am watching someone else.
g) I feel like the finger belongs to me.

h) I feel like the finger is under my control.
i) I feel like my hand is longer than normal.
j) I feel like my hand is shorter than normal.

2.5 Stretched hand

a) I felt like my hand was really being stretched.
b) I felt like my hand was really being shrunken.
c) I feel like my hand is longer than normal.
d) I feel like my hand is shorter than normal.
e) I feel like I am watching myself.
f) I feel like I am watching someone else.
g) I feel like the hand belongs to me.
h) I feel like the hand is under my control.
i) I feel like my finger is longer than normal.
j) I feel like my finger is shorter than normal.

2.6 Shrunken hand

a) I felt like my hand was really being shrunken.
b) I felt like my hand was really being stretched.
c) I feel like my hand is shorter than normal.
d) I feel like my hand is longer than normal.
e) I feel like I am watching myself.
f) I feel like I am watching someone else.
g) I feel like the hand belongs to me.
h) I feel like the hand is under my control.
i) I feel like my finger is longer than normal.
j) I feel like my finger is shorter than normal.

2.7 Detached condition

a) I felt like the tip of my finger had become detached from the rest of my finger.
b) I feel like the detached part belongs to me.
c) I feel like I am watching myself.

Illusion strength and ownership statements for Chapters 4, 5 and 6 were adapted from this list.

Appendix 3: Psychometric scales

3.1 Somatosensory Amplification Scale (SSAS; Barsky, Goodson, Lane & Cleary, 1988)

Instructions: Please state the degree to which the following statements are characteristic of you in general.

1 = Not At All True
2 = A Little Bit True
3 = Moderately True
4 = Quite A Bit True
5 = Extremely True

1.	When someone else coughs, it makes me cough too	1	2	3	4	5
2.	I can't stand smoke, smog, or pollutants in the air	1	2	3	4	5
3.	I am often aware of various things happening within my body	1	2	3	4	5

4.	When I bruise myself, it stays noticeable for a long time	1	2	3	4	5
5.	Sudden loud noises really bother me	1	2	3	4	5
6.	I can sometimes hear my pulse or my heartbeat throbbing in my ear	1	2	3	4	5
7.	I hate to be too hot or too cold	1	2	3	4	5
8.	I am quick to sense the hunger contractions in my stomach	1	2	3	4	5
9.	Even something minor, like an insect bite or a splinter, really bothers me	1	2	3	4	5
10.	I have a low tolerance for pain	1	2	3	4	5

3.2 State-trait anxiety inventory- Trait scale (STAI-T; Spielberger, Gorsuch & Lushene, 1970)

Instructions: A number of statements which people have used to describe themselves are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate how you generally feel. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe how you generally feel.

1 = not at all 2 = somewhat 3 = moderately so 4 = very much so

1	I feel calm	1	2	3	4
2	I feel secure	1	2	3	4
3	I am tense	1	2	3	4
4	I feel strained	1	2	3	4
5	I feel at ease	1	2	3	4
6	I feel upset	1	2	3	4
7	I am presently worrying over possible misfortunes	1	2	3	4
8	I feel satisfied	1	2	3	4
9	I feel frightened	1	2	3	4
10	I feel comfortable	1	2	3	4
11	I feel self-confident	1	2	3	4
12	I feel nervous	1	2	3	4
13	I am jittery	1	2	3	4
14	I feel indecisive	1	2	3	4
15	I am relaxed	1	2	3	4
16	I feel content	1	2	3	4
17	I am worried	1	2	3	4
18	I feel confused	1	2	3	4
19	I feel steady	1	2	3	4
20	I feel pleasant	1	2	3	4

3.3 Somatoform Dissociation Questionnaire-20 Trait scale (SDQ-20; Nijenhuis, Spinhoven, VanDyck, VanderHart & Vanderlinden, 1996)

This questionnaire asks about different physical symptoms or body experiences, which you may have had either briefly or for a longer time. Please indicate to what extent these experiences apply to you in the past year.

For each statement, please circle the number in the first column that best applies to YOU.

The possibilities are:

The possibilities are:

1 = this applies to me NOT AT ALL

2 = this applies to me A LITTLE

3 = this applies to me MODERATELY

4 = this applies to me QUITE A BIT

5 = this applies to me EXTREMELY

If a symptom or experience applies to you, please indicate whether a physician has connected it with a physical disease. Indicate this by circling the word YES or NO in the column "Is the physical cause known?" If you wrote YES, please write the physical cause (if you know it) on the line.

Example:

	Extent to which the symptom or experience applies to you	Is the physical cause cause known?	
Sometime:			
My teeth chatter	1 2 3 4 5	NO	YES, namely
I have cramps in my calves	1 2 3 4 5	NO	YES, namely

If you have circled a 1 in the first column (*i.e.*, This applies to me NOT AT ALL), you do NOT have to respond to the question about whether the physical cause is known.

On the other hand, if you circle 2, 3, 4, or 5, you MUST circle No or YES in the "Is the physical cause known?" column.

Please do not skip any of the 20 questions.

Here are the questions:

		Extent to which the symptom or experience applies to you					Is the physical cause cause known?	
Sometimes:								
1	I have trouble urinating	1	2	3	4	5	No	Yes, Namely….
2	I dislike tastes that I usually like (women: at times OTHER THAN pregnancy or monthly periods)	1	2	3	4	5	No	Yes, Namely….
3	I hear sounds from nearby as if they were coming from far away	1	2	3	4	5	No	Yes, Namely….
4	I have pain while urinating	1	2	3	4	5	No	Yes, Namely….
5	My body, or a part of it, feels numb	1	2	3	4	5	No	Yes, Namely….

6	People and things look bigger than usual	1	2	3	4	5	No	Yes, Namely….
7	I have an attack that resembles an epileptic seizure	1	2	3	4	5	No	Yes, Namely….
8	My body, or a part of it, is insensitive to pain	1	2	3	4	5	No	Yes, Namely….
9	I dislike smells that I usually like	1	2	3	4	5	No	Yes, Namely….
10	I feel pain in my genitals (at times OTHER THAN sexual intercourse)	1	2	3	4	5	No	Yes, Namely….
11	I cannot hear for a while (as if I am deaf)	1	2	3	4	5	No	Yes, Namely….
12	I cannot see for a while (as if I am blind)	1	2	3	4	5	No	Yes, Namely….
13	I see things around me differently than usual (for example as if looking through a tunnel, or seeing merely a part of an object)	1	2	3	4	5	No	Yes, Namely….
14	I am able to smell much BETTER or WORSE than I usually do (even though I do <u>not</u> have a cold)	1	2	3	4	5	No	Yes, Namely….
15	It is as if my body, or a part of it, has disappeared	1	2	3	4	5	No	Yes, Namely….

16	I cannot swallow, or can swallow only with great effort	1	2	3	4	5	No	Yes, Namely….
17	I cannot sleep for nights on end, but remain very active during daytime	1	2	3	4	5	No	Yes, Namely….
18	I cannot speak (or only with great effort) or I can only whisper	1	2	3	4	5	No	Yes, Namely….
19	I am paralysed for a while	1	2	3	4	5	No	Yes, Namely….
20	I grow stiff for a while	1	2	3	4	5	No	Yes, Namely….

3.4 Psychometric scales and EHI scores

Chapter	Experiment	Edinburgh Handedness Inventory (EHI)		Somatoform Dissociation Questionnaire- 20 (SDQ-20)		Somatosensory Amplification Scale (SSAS)		State Trait Anxiety Inventory- Trait (STAI-T)	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range
Chapter 3	3.1	80	41-100	-	-	-	-	-	-
Chapter 4	4.2 (Exp 1)	72	41-100	-	-	-	-	-	-
	4.6 (Exp 2)	66	41-94	-	-	-	-	-	-
	4.10 (Exp 3)	68	41-100	-	-	27	13-38	43	24-55
Chapter 5	5.2 (Exp 1)	72	41-100	-	-	30	19-40	39	20-66
	5.6 (Exp 2)	70	41-100	-	-	29	21-40	40	22-55
	5.10 (Exp 3)	64	42-93	28	20-48	31	18-42	40	24-60
Chapter 6	6.1	69	42-100	31	20-58	-	-	-	-

* Please note, EHI scores above 40 = right handed.

Appendix 4: Stimulus array of Somatic Signal Detection Task

4.1 Electromagnetic solenoid stimulator (Tactor)

The tactor is designed to be attached to the skin, clothing items or even other objects via adhesive tape. Tactors can deliver tactile stimuli ranging between zero and 300Hz. The amplitude of the vibration varies linearly with voltage resulting in it being able to create stimuli of various strengths. By this view the tactor behaves as a tactile-speaker. The tactor could be operated via the TactAmp or via audio amplifiers.

4.2 TactAmp

The TactAmp consists of a four channel – amplifier and can therefore be connected to four tactors simultaneously. It also contains 4 LED ports. The amplifier controls the amplitude of the vibrotactile stimuli.