The Real Hand Illusion: Inducing Disownership of the Biological Limb in Virtual Reality and the Involvement of Right Parietal Cortex

by

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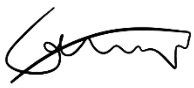

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ABSTRACT

'What does it mean to own a body?' is a fundamental question regarding the nature of the self. The bottom-up perceptual and higher order processes of how we distinguish what is our own body from the environment have been of great interest in recent years. The now classical 'rubber hand illusion' revealed how embodiment of a like life rubber hand can be achieved through manipulating visuo-tactile information. However, the RHI and subsequent iterations have often failed to replicate the phenomenology of disorders such as Xenomelia and Somatoparaphrenia, where individuals do not report ownership of a limb(s), rather than the misattribution of ownership to an extrabodily object. Therefore, we have developed the 'Real Hand Illusion', which endeavours to reduce ownership of one's own biological limb through a virtual reality illusion. Participants viewed their hand being stroked by a paintbrush in the virtual environment, in the illusory condition, there was a 400ms visual latency leading to a disruption of multisensory integration. Feelings of ownership were reduced in the illusory condition as measured by a self-report questionnaire generated by the researchers. We also sought to investigate whether right parietal regions are involved in the processing of multisensory data, as has been suggested through clinical cases of individuals with body ownership disorders. Electrical stimulation of the P4 region using tDCS successfully modulated feelings of ownership. Cathodal stimulation conditions resulted in significantly higher sensations of ownership than anodal conditions. We have therefore developed a novel virtual paradigm which more closely reflects the phenomenology of disorders such as Xenomelia. We have also provided further evidence for the involvement of right sided parietal regions in processing multisensory information, and subsequently leading to feelings of ownership.

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ABBREVIATIONS

HMD – Head Mounted Display

IPL – Inferior Parietal Lobe

IVR – Immersive Virtual Reality

rTMS – Repeated Transcranial Magnetic Stimulation

ReHI – Real Hand Illusion

RHI – Rubber Hand Illusion

SKR – Skin Conductance Response

SPL – Superior Parietal Lobe

tDCS – Transcranial direct-current Stimulation

tES – Transcranial Electrical Stimulation

TMS – Transcranial Magnetic Stimulation

VR – Virtual Reality

Tables and Illustrative material

INTRODUCTION

How individuals perceive their own bodies, and how they discriminate their 'self' from the external environment, is fundamental to self-awareness (Serino et al., 2013). Humans experience themselves through a first-person perspective, whilst simultaneously embodying their physical body (Brugger & Lenggenhager, 2014). The seamless experience of one's bodily space is the result of the interaction between interoceptive, exteroceptive and proprioceptive information (Brugger & Lenggenhager, 2014). A central facet to the experience of the self is that of bodily ownership. This is the pre-reflective sensation that the body we exist in, is inexplicably 'mine' and that it is distinct from the world around it (Serino et al, 2013). Contemporary neuroscience has focused on the mechanisms which evoke the feelings of bodily ownership and how such processes contribute to the experience of the bodily self. The understanding of these concepts has been driven by two primary methods of investigation. Firstly, through pathological disorders of the bodily self, where individuals may lose ownership of their own limbs. Secondly, through perceptual illusion paradigms in healthy populations, which acutely modulate sense of ownership to extrabodily objects. These experimental findings in healthy individuals stem from the classical 'Rubber Hand Illusion' (RHI) (Botvinick & Cohen, 1998), which modulated ownership of the participants' hand to a rubber hand by manipulating multisensory integration. Such paradigms have elucidated how one may modulate ownership to a foreign body, however, they often fail to explicate the mechanisms of disownership in the real hand. Crucially, such mechanisms may reveal the aetiology of disorders where bodily ownership is disturbed, more specifically, where ownership of specific limbs is non-existent. Therefore, the current research aims to produce a novel paradigm which more closely resembles the phenomenology of disorders such as Xenomelia and Somatoparaphrenia in comparison to classical RHI paradigms. This will be achieved through a virtual reality paradigm we have developed, known as the 'Real Hand Illusion' (ReHI), which will induce feelings of disownership by disrupting the congruency of visuo-tactile feedback. Participants will view their own hand being stroked by a paintbrush in the virtual environment, a visual delay will be implemented which will disturb integration of what the participant sees and feels, leading to disownership of the viewed hand. Feelings of ownership, disownership and agency of the hand will be measured by a self-report questionnaire generated by the researchers. Further to this, using transcranial direct-current stimulation, the study aims to provide a causal link between ride side parietal regions and limb ownership resulting from multisensory integration. The thesis will provide a summary of classical rubber hand illusions, and how they have contributed to our understanding of how sensory information is processed and how that leads to feelings of ownership. The thesis will also assess how further studies how higher order functions contribute to our phenomenological sensation of the self. Furthermore, it will also review how both experimental and clinical evidence have revealed brain regions implicated in the processing and integration of multisensory information. The studies revealed that disruption of visuo-tactile information through the illusory condition reduced feelings of ownership in one's biological limb. We also report stronger illusory effects of the asynchronous condition in the left hand compared to the right. Furthermore, tDCS was successfully able to modulate illusory strength, with anodal stimulation significantly attenuating feelings of ownership compared to cathodal stimulation. Finally, the thesis will discuss the potential implications of the findings, and how these findings will contribute to our knowledge of bodily ownership in healthy and unhealthy individuals.

Body ownership and the classical Rubber Hand Illusion

As mentioned previously, body ownership appears to be a crucial facet involved with constructing a complete sense of the 'self' (Jeannerod, 2003). Recent research has focused on revealing the core processes which contribute to feelings of ownership. The aforementioned study, the 'Rubber hand illusion' (Botvinick & Cohen, 1998), provided key insights into how ownership may be produced through illusions which reveal the workings of perceptual processes. Participants viewed a rubber hand placed in an anatomically congruent position as their actual hand (which was occluded from view). The researchers provided tactile stimulation through paintbrush stroking on the back of the real and simultaneously on the rubber hand. In one condition, the paintbrush strokes on the rubber and real hand were performed in synchrony with one another, so the participant viewed brush strokes being made at the same time as feeling them. In the other condition, brush strokes on the rubber and real hand were performed asynchronously. The questionnaire included questions related to participants' perceived ownership of the rubber hand, with participants giving significantly higher ratings of ownership to the rubber hand when viewed brush strokes were congruent with what was felt. According to the researchers, the illusion was a result of multisensory (visuo-tactile) conflict being resolved, with participants recalibrating ownership of their limb to the rubber hand. The landmark study ignited interest in how individuals perceive visual and somatosensory information and how this leads to a seamless ownership of the self (Ramakonar, Franz & Lind, 2011).

Early theories of bottom-up processing in RHI

Botvinick & Cohen (1998) stated that the multisensory processing of afferent information attempts to unify disparate information, and that congruency between visuo-tactile information was adequate to modulate ownership to even a non-corporeal object. This would assume, that body ownership is malleable, and in the case of the RHI, can be modulated by altering information involved in bottom-up processing. Reproductions of the RHI provided further evidence which supported a strictly bottom-up explanation. For example, Armel & Ramachandran (2003) reported that participants produced significantly higher skin conductance responses following 'injury' when the RHI was applied to non-corporeal objects such as a table as well as lifelike objects such as the rubber hand. A higher skin conductance response indicates greater levels of implicit ownership to the object (see section on implicit ownership). Additional to this, the researchers reported that ownership was achieved in the rubber hand in anatomically impossible positions. This may suggest that rather than ownership arising from resolving multisensory conflict, feelings of ownership are driven by the integration of congruent visuo-tactile information. Interoceptive information such as proprioception may be a secondary factor which facilitates or enhances these feelings.

Limitations of bottom-up processing

Conversely, the concept that congruent visuo-tactile stimulation is adequate to modulate the phenomenological sensation of ownership, even to non-corporeal objects, has subsequently been debated. Several studies have reported that the RHI is unsuccessful on objects which are inconsistent with one's reference model of the body. For example, Tsakiris et al (2009) systematically altered the appearance of the extrabodily object, initially as a wooden block, then wooden hand and finally a rubber hand. Only the rubber hand was susceptible to the RHI, indicating that modulating ownership may also require a structural appearance which is congruent with bodily representations. Additionally, congruency of posture, and proprioceptive information, may also limit the effectiveness of the RHI. Rubber hands placed at perpendicular angles to the real hand did not evoke a significant sensation of ownership in the RHI (Tsakiris & Haggard, 2005). Further studies, such as Lloyd (2007) have defined the spatial limits regarding rubber hand distance and illusory strength. When the rubber hand distance exceeds 30cm, the strength of illusion is significantly reduced (Lloyd, 2007). This may be due to the rubber hand exiting the peripersonal space, which is defined by the visuo-tactile receptive field generated by bimodal neurons in parietal regions (Graziano & Gross, 1995). It is therefore apparent that bottom-up processes are a necessary prerequisite to produce the illusion. Further to this, top-down processes which compare the seen object with one's own bodily representations modulate the phenomenological experience of ownership.

Implicit and Explicit measures of ownership and self-location

It is also important to note what level of ownership RHI paradigms are affecting and measuring. Candini et al. (2016) and Fossataro et al, (2016) describe implicit and explicit ownership as disparate concepts. Explicit levels of ownership, namely the participant's phenomenological experience of the illusion, can be measured through self-report questionnaires (Botvinick & Cohen, 1998). Longo et al. (2008) conducted a study to define the specific components that form the phenomenology of rubber hand ownership. A principal component analysis of a limb ownership questionnaire revealed that location (feeling of rubber and real hand being in same location), ownership (feeling that the rubber hand was part of participant's body) and agency (participants felt they had motor control over rubber hand) were concomitant with the synchronous condition.

Additionally, ownership can be experienced and measured at an implicit level by observing physiological self-regulatory changes in the RHI. Tsuji et al. (2015) reported that a blow to the rubber hand with a hammer resulted in significantly higher skin conductance responses (SKR) (in the real hand) in the synchronous condition. Increased perspiration is linked with the autonomic nervous system responding to a potential threat (Hare et al, 1978). Skin conductance responses in the RHI therefore suggest participants implicitly experience a threat in the rubber hand as if it was their own. Further physiological responses such as skin temperature (Moseley et al, 2008., Thakkar et al, 2011), histamine response (Barnsley et al, 2011) and blood flow (Chae et al, 2014) have all been modulated within the RHI. Interestingly, it appears that implicit changes are driven by bottom-up processing of visuo-tactile information. This may explain, for example, why Armel & Ramachandran (2003) reported ownership being significantly higher in implicit measures compared with explicit measures when ownership was modulated to a non-corporeal object.

The RHI paradigm has also been used to assess how the illusory condition affects one's proprioceptive judgements of their limb, i.e. their perceived sense of location in space (Botvinick & Cohen, 1998). Using the 'proprioceptive drift' measure, participants are asked to point, with their non-affected hand, where they believed their occluded hand to be. Synchronous stroking resulted in participants judging their hand to be closer to the rubber hand (Botvinick & Cohen, 1988). Fuchs et al (2016) demonstrated that the recalibration of one's proprioceptive percept was due to a multisensory compromise between visuo-tactile and proprioceptive information. The measure is often used as a measure of illusory strength of the RHI (Fuchs et al, 2016).

Neurocognitive explanation of ownership

Tsakiris (2010) has put forward the most established model to explain limb ownership in the RHI which encompasses both multisensory integration and one's implicit knowledge of their body model. In the initial stage of the model, the external object is reviewed as to whether its visual appearance, i.e. structure and volume, is consistent with the established body model. Tsakiris (2010) argues that the initial top-down visual test prevents non-corporeal objects from being erroneously incorporated to the 'self'. It is argued that objects that more closely resemble the human form, will produce stronger sensations of ownership. Furthermore, this is likely to be based on a body model, rather than image, as visual attributes such as skin colour do not affect rubber hand illusory strength (Longo et al, 2009). Despite this, previous RHI studies (Armel & Ramachandran, 2003) and more recent virtual reality illusions (Ma & Hommel, 2015), have successfully attributed ownership to non-corporeal objects. Ma & Hommel (2015) state that embodiment of non-cororeal objects becomes possible when one is able to manipulate the features and behaviour of the object in-line with their intentions. Therefore, it may be possible for agency to modulate embodiment in the absence of an object that is structurally inconsistent with the established body model.

Tsakiris (2010) further states that once these visual characteristics have been validated with the body model, postural information is compared with reafferent information. Costatini & Haggard (2007) showed that postural and anatomical information are required to be consistent with one's proprioceptive feedback for embodiment to be successful, this is true even when visuo-tactile information is congruent. The final requirement for embodiment, is for visuo-tactile information to be established as congruent. Conflicts in what is seen and felt in the rubber hand prevent the establishment of ownership to an external object (Botvinick & Cohen, 1998).

Interoceptive awareness and RHI illusory strength

Interoceptive information such as proprioception is a key component of the bodily self and self-location (Botvinick & Cohen, 1998., Tsakiris, 2010). It has been suggested that those who have higher levels of interoceptive awareness may process interoceptive and exteroceptive information to others. This may explain why illusory strength of the RHI is so diverse across a participant cohort. The literature has investigated whether interoceptive awareness predicts illusory strength with conflicting reports. Researchers have used the 'heartbeat tracker' task, where participants press a key every time they feel their hear beat, those who more accurately log the beats of their heart are linked with greater interoceptive awareness (Knapp-Kline & Kline, 2005) The task has been shown to suggest that those with low interoceptive awareness experience higher illusory effects of the RHI (Tsakiris, Jimenez & Costantini, 2011). It may be that some individuals are able to focus more attentional resources to multi-sensory processing compared to interoceptive monitoring (Tsakiris, Jimenez & Costantini, 2011). Conversely, more recent research has failed to replicate the heartbeat tracker as a predictor of illusory strength (Crucianelli, Krahé, Jenkinson & Fotopoulou, 2017). Moreover, alternative measures such as body awareness questionnaires have not been able to predict illusory strength (David, Fiori & Aglioti, 2013).

Associated brain regions

Stemming from early RHI studies, researchers have attempted to correlate processes of ownership and embodiment with the responsible brain regions. Ehrsson (2004) used fMRI scans to elucidate brain regions which may be involved in integrating multisensory data. The data revealed that illusory strength of the RHI strongly correlated with activation of the pre-motor cortex (PMC). This area may well be involved in generating sensations of ownership, as it has been suggested that the region plays a vital role in engendering one's reference of the body's peripersonal space (Fogassi et al. 1996). Ehrsson (2004) suggests that the PMC is unifying the disparate tactile and proprioceptive information to the seen visual stimulus. However, electrical stimulation of the PMC has been shown to cause defensive motor actions, suggesting a role in detection of objects in the peripersonal space (Graziano, Taylor & Moore, 2002). Therefore, activation of this region in the RHI may not be from the realignment of one's body reference, but rather objects entering the peripersonal area. In response to this, Ehrsson, Holmes & Passingham (2005) conducted a further fMRI study with an altered RHI paradigm that was based solely on somatic information. PMC activation was once again positively correlated with illusory strength, reaffirming Ehrsson's (2004) argument that the region is responsible for unifying multisensory information to ameliorate sensory conflict.

Other regions of interest which may contribute to multisensory integration are the parietal cortices (Tsakiris, 2010). Firstly, it has been suggested that the left inferior parietal lobe (IPL) may play a role in judgements of localisation of one's own body (Kammers et al, 2009). Repetitive stimulation of the left IPL prior to undertaking the RHI led to reductions in proprioceptive drift but not sensations of ownership in the rubber hand. The study suggests that embodiment of extra-bodily objects and judgements of localisation in one's own body are dissociable processes. Further interest in parietal regions has been driven by research with individuals who suffer from disturbances of the bodily self. McGeoch et al (2011) used magnetoencephalography (MEG) scans to reveal regions that may be of interest in individuals with Xenomelia (see next section for more information on Xenomelia). Tactile stimulation of deafferented regions of the participants' bodies led to significantly reduced activation in the right superior parietal lobe (SPL). The researchers suggest that lack of right SPL activation may lead to tactile sensations not being matched by a normal body model and subsequently leading to desire for amputation. Further investigation by Hilti et al (2012) used magnetic resonance imaging (MRI) to assess whether individuals with Xenomelia were characterised by structural differences in cortical regions. Scans revealed reduced cortical thickness in the right SPL, further implicating the region in the onset of disturbances of the bodily self.

Evidence from electrophysical data (Press, Heyes, Haggard & Eimer, 2008) and neuropsychological cases (Martinaud, Besharati, Jenkinson & Fotopoulou, 2017) proposes that judgements on corporeability of extra-bodily objects and multisensory integration are disparate activities in the RHI. Further research has suggested that the right temporoparietal junction (rTPJ) may play a role in embodiment by assessing the compatibility of the object with one's body model (Tsakiris, 2010). This mainly stems from individuals who do not report ownership of their own biological limb(s), as damage to temporoparietal regions is usually concomitant (Feinberg, Venneri, Simone, Fan & Northoff, 2009). By using transcranial magnetic stimulation (TMS) on the rTPJ, Tsakiris, Costantini & Haggard (2008) reduced sensations of rubber hand ownership in the RHI as measured by proprioceptive drift. More importantly, feelings over ownership in the rubber hand were comparable to that of a neutral object. These results suggest that judgements of object corporeability were impaired, leading to any ownership misattribution being solely driven by bottom-up processes. Therefore, the researchers argue that the rTPJ may act as a region which compares internal bodily states with afferent multisensory information.

As ownership can be experienced at a phenomenological and implicit level, researchers have sought to reveal which brain region(s) may be responsible for the subjective experience of ownership. Tsakiris (2010) reports that the activation of the right insular is strongly correlated with strength of proprioceptive drift in the RHI. The right insula appears a likely candidate due to its involvement in interoception (Craig, 2009), with interoceptive sensitivity being a predictor of body ownership malleability (Tsakiris, Jimenez & Costantini, 2011). Additionally, the region has been implicated in processing one's recognition of their 'self' (Devue et al., 2007). More direct evidence has shown that individuals who display anosognosia for hemiplegia who also have legions of the right insula leads to the abolition of ownership of contralateral limbs in addition to lack of awareness (Karnath & Baier, 2010).

Pathological disorders of disownership

Much of the literature has focused on the underlying processes involved in the embodiment of a foreign object, usually a supernumerary hand (Longo et al., 2008). This is despite many disorders of the 'self' often involving loss of ownership in biological limbs, rather than misattribution to extra-bodily objects (Longo et al., 2008). One such disorder, Somatoparaphrenia, was originally described as individuals who displayed hemi-spatial neglect of a limb(s) and used confabulations to reason the limb's existence (Gerstmann, 1942). Additionally, individuals with somatoparaphrenia usually exhibit neglect of the left side of the body, and this is often accompanied by paralysis (Vallar & Ronchi, 2009). Furthermore, this appears to be largely caused by deficits in proprioceptive information rather than visual and somatosensory deficits (Vallar & Ronchi, 2009). Recent neuropsychological studies have attempted to reveal the aetiology of the disorder, which is currently, poorly understood (Feinberg & Venneri, 2014). Evidence from case studies appears to suggest right sided brain damage, usually from stroke, may result in a disturbed sense of ownership of one's limb(s) (Bartolomeo, de Vito & Seidel Malkinson, 2017).

Additional disorders of the *self* exist, with many sharing similar characteristics, one of which being Xenomelia, or body identity integrity disorder (BIID). Brugger et al (2013) describes the rare and dramatic disorder as the rejection of one or more limbs from one's body and the desire for amputation. Sufferers appear to have a body which is 'overcomplete' in comparison to their body model, as well as implicitly viewing amputees as having a preferable body type (Macauda, Bekrater-Bodmann, Brugger & Lenggenhager, 2017). As mentioned previously, the it's been suggested that the aetiology may lie with abnormalities of right sided parietal regions (McGeoch et al., 2011, Hilti et al., 2012). Right sided parietal regions may be involved in the integration of multisensory information, and disturbances in this process may lead to feelings of disownership towards a biological limb as seen in Xenomelia (Lenggenhager, Hilti & Brugger, 2015). More recently however, researchers have suggested that influence of social and cultural factors may be involved in the onset of limb non-acceptance (Brugger et al, 2013). For instance, it may be the case that individuals with Xenomelia are hyper-sensitive to social mimicry, and that key life experiences with amputees lead to unconscious mimicking of posture, mannerisms and behaviours (Brugger et al., 2013, Van Baaren, Janssen, Chartrand & Dijksterhuis, 2009).

Due to these disorders being comparatively rare, modern Neuroscience has sought to understand them through illusory paradigms in healthy participants. Current paradigms such as the RHI however, are more concerned with processes of embodiment to a supernumerary hand and may neglect processes of embodiment in the biological hand (Vignemont, 2011). It may be that researchers assume the *unified account theory*, which states as sensations and judgements of ownership decrease, disownership increases (Vignemont, 2011). However, Vignemont (2011) argues that ownership lacks a sense of intensity, and that in order to experience disownership, one must notice interruptions in embodiment of the self. Evidence for the *discovery theory* is supported by pathological disorders such as those who display anosognosia for hemiplegia. In this case, individuals are not aware they are paralysed, as deficits in sensorimotor information are not likely to be overtly noticeable (Levine et al, 1991). Therefore, one must consciously observe one's own body to detect abnormalities of the self. Furthermore, proprioceptive and nociceptive sensations of a limb are common both acutely and chronically following its amputation (Ramachandran, 1998). Thus, it is further evident that disturbances of the self are often incorrectly processed leading to anosognosia or a phenomenological sensation that inaccurately reflects the disease. It could therefore be argued that RHI paradigms are insufficient in elucidating how pathological accounts of limb disownership arise. Rather, if ownership and disownership can arise independently, as argued by the *discovery model*, then researchers must attempt to create illusory paradigms which systematically augment disownership in the biological limb.

Virtual Reality Techniques

Since the inception of the RHI with Botvinick & Cohen (1998), the paradigm has been continually replicated. More recently, research has utilised immersive virtual reality (IVR) to reproduce the illusory paradigm. IVR is of great use as an investigative tool, as it has the ability to specifically modulate sensory information in the virtual environment (Sanchez-Vives & Slater, 2005). This has allowed the RHI paradigm to have been successfully replicated in the virtual environment (Yuan & Steed, 2010). Furthermore, it has been shown that IVR produces a more intense subjective experience of the RHI (IJsselsteijn, de Kort & Haans, 2006). Additional to virtual hand embodiment, IVR has allowed for full body ownership paradigms to be possible. When participants observe a stereoscopic 3D projection of themselves being stroked synchronously, they mislocalised their bodily self towards the projection (Ehrsson., 2007, Lenggenhager et al., 2007).

Transcranial direct current stimulation

As part of the research, we have opted to use transcranial direct current stimulation (tDCS) as an investigative tool. tDCS is a non-invasive neurostimulation device which acts by passing a weak current between two electrodes, a cathode and an anode (Nitsche et al, 2008). The two electrodes are placed on the scalp, the current flows between the electrodes, with some of the current diverting through to cortical regions of interest (Nitsche et al, 2008). The purpose of the stimulation is to modulate brain activity of a targeted area, subsequently modulating a particular behaviour. tDCS functions by altering threshold levels of neuronal membranes (Priori, Hallett & Rothwell, 2009). Anodal stimulation of cortical regions reduces the threshold at which the neuron depolarises (Brunoni et al, 2012). In turn, this increases spontaneous cortical activity at the location of stimulation. Cathodal stimulation has the opposite effect, causing lower levels of spontaneous activity through increasing depolarisation thresholds (Brunoni et al, 2012).

Rationale

Contemporary research thus far has focused on how ownership may arise through manipulating visuo-tactile information. In cases such as the RHI, embodiment of a supernumerary hand is achieved through unifying the visual stimulus of the paintbrush being stroked on the rubber hand and the felt stimulus of the brush stroking on the biological hand. The various RHI paradigms have revealed key processes of how ownership arise, i.e. through congruent visuo-tactile and proprioceptive information, as well as corporeality of the object. However, these studies appear to neglect processes of disownership in the biological hand. Crucially, many disorders which affect one's experience of the bodily self are consequential of disownership in a biological limb(s), such as Xenomelia. Therefore, it appears necessary that a paradigm shift is required, such that behavioural paradigms more closely reflect the phenomenology of said disorders.

In response to this, we have developed the 'real hand illusion', a novel virtual reality paradigm which endeavours to increase feelings of disownership in the biological hand. Participants will view their hand in a virtual environment whilst wearing the HMD. They will observe their hand being stroked by a paintbrush, in a similar fashion to the RHI. In the illusory condition, visual feedback of the paintbrush stroking will be delayed, in an effort to disrupt contiguity of visuo-tactile feedback. Feelings of ownership will be measured by a self-report questionnaire generated by the researcher. Furthermore, there is conflicting evidence as to whether interoceptive awareness is a predictor of sensitivity to the RHI (Crucianelli, Krahé, Jenkinson & Fotopoulou, 2017., Tsakiris, Jimenez & Costantini, 2011). However, there appears to be no literature which has investigated a potential link between interoceptive awareness, and disownership through perceptual illusions. Therefore, we will ask participants to complete the Body Perception Questionnaire Short Form (BPQSF) (Porges, 1993, 2015) (Appendix 2). This questionnaire will include questions related to participants' bodily awareness. This may reveal whether interoceptive awareness also predicts illusory strength regarding disownership of the biological hand. Finally, due to lower levels of malleability being reported in the right hand in the RHI (Ocklenburg, Rüther, Peterburs, Pinnow & Güntürkün, 2011), we will investigate whether the same is true in the ReHI. Consequently, the main aim of the behavioural element of the research, is to develop a more suitable paradigm which more closely resembles disorders such as Xenomelia.

Additional to the behavioural study, we aimed to provide further evidence that disorders such as Xenomelia are rooted in right sided parietal abnormalities. Xenomelia is most often a left sided disorder (Hilti et al, 2012), suggesting a right sided dominance for body ownership. Additionally, MEG data in clinical populations revealed significantly reduced activation of right parietal regions when deafferent regions received tactile stimulation (McGeoch et al., 2011). Therefore, we will use tDCS (transcranial direct current stimulation) as a tool to investigate whether right parietal regions are responsible for the integration of visuo-tactile information in the ReHI. The significance of this is that tDCS allows a causative relationship to be established between brain regions and human behaviour. The rationale for choosing tDCS over TMS (transcranial magnetic stimulation) was primarily due to its ability keep participants naïve to sham conditions. Further reasons for its use are that it is more comfortable, safer and easier to handle than TMS (Romero Lauro et al., 2014). If tDCS can successfully modulate illusory strength of the ReHI, it will be further implicated in generating feelings of bodily ownership through the processing of exteroceptive information.

Hypotheses

Pilot study

The pilot study will use a cohort of 20 right-handed participants from the University of Central Lancashire. The primary objective of the pilot study will be to assess whether the ReHI is able to reduce feelings of ownership in the biological hand. Participants will take part in both the control and illusory conditions of the ReHI on their right hand. Due to previous evidence using the RHI paradigm (Botvinick & Cohen, 1998) and subsequent VR study evidence (Yuan & Steed, 2010, Ehrsson., 2007, Lenggenhager et al., 2007), we predict that the asynchronous paintbrush stroking will result in significantly lower levels of ownership in the illusory condition, as measured by a self-report questionnaire (Appendix 4).

Study 1 (Behavioural)

Study 1 will have its participant sample number determined following the effect size reported in the pilot study with a power of 95%. In study 1, participants will take part in both the control and illusory conditions in each hand. Laterality studies of the RHI have shown only implicit levels of ownership to show laterality differences (Ocklenburg, Rüther, Peterburs, Pinnow & Güntürkün, 2011). However, this paradigm more closely resembles the phenomenology of Xenomelia, which has a significantly higher incidence of ownership loss in left sided limbs (Hilti et al, 2012, McGeoch et al., 2011). We therefore predict that the ReHI will cause greater losses of ownership in the biological limb in the left hand compared to the right.

There have been conflicting reports of whether interoceptive is a predictor of illusory strength in the RHI (Crucianelli, Krahé, Jenkinson & Fotopoulou, 2017., Tsakiris, Jimenez & Costantini, 2011). Despite this, we expect the ReHI to have stronger illusory effects than classical RHI paradigms and believe this gives a significantly higher chance of revealing any potential relationship. Therefore, we predict that interoceptive awareness, as measured by the body perception questionnaire (Appendix 2), will be a predictor of a participant’s sensitivity to the ReHI, as measured by illusory strength. More specifically, we expect those with low interoceptive awareness scores to experience higher levels of disownership in the ReHI.

Study 2 (Neurostimulation)

It has previously been reported that neurostimulation techniques have been successful in modulating illusory strength of the RHI (Kammers et al, 2009). The right SPL has been implicated in the aetiology of Xenomelia possibly through incorrect integration of multisensory information

(McGeoch et al, 2011). Study 2 will therefore use transcranial direct current stimulation (tDCS) both anodally and cathodally over the P4 region. The P4 region has been used previously as a tDCS locus for investigating right SPL functions (Ono, Mikami, Fukuyama & Mima, 2015). As feelings of disownership have been linked with insufficient activation of the right SPL (McGeoch et al, 2011), then we predict that anodal stimulation conditions will results in higher levels of perceived ownership than sham and cathodal conditions.

METHODS

Study 1 (Behavioural)

Pilot Data

A pilot study of the behavioural paradigm (N = 20, age = 21 ± 1 years, 8 male & 12 females) was conducted to assess the illusory strength of the virtual paradigm. Participants reported their subjective experience of the virtual hand through a self-report questionnaire. The 10 questions were rated using a banded VAS scale between 0-10. A banded VAS scale was chosen to reduce the bias of VAS slider decorations (Matejka, Glueck, Grossman & Fitzmaurice, 2016). Questions 7-10 had their directions reversed due to questions being related to disownership. Participants' scores were established using the mean of the 10 questions. A t-test was used to compare the synchronous stroking condition with the asynchronous condition and subsequently revealed a highly significant effect ($t(19) = 4.58$, $p < 0.001$, Cohen's $dz = 1.02$). Mean questionnaire scores decreased from 7.75 ± 1.31 in the asynchronous condition to 5.85 ± 1.73.

Participants

Following the large effect size of the pilot study, only 15 participants would be required to produce the same effect size with 95% power and an alpha of 0.05. *N*=20 participants, all of which were students at the University of Central Lancashire were recruited for the study via opportunity and volunteer sampling. 10 males and 10 females participated with a mean age of 21.55 (SD = 2.48). Participants were required to be over 18, right handed and are able to see in stereoscopic 3D. Participants were informed before the study that they would be compensated with an Amazon voucher to the value of £5. To prevent adverse events resulting from using the virtual reality headset, a short screening questionnaire was included in the participant briefing (see Appendix 1).

Ethical approval

This study was approved by the University of Central Lancashire's Ethical committee (Unique code: PSYSOC336).

Protocol

Participants were greeted upon arrival and were given a briefing (Appendix 1) which outlined the general aims and protocol of the study. Participants then completed the screening questionnaire and had the opportunity to sign consent. Participants were reminded before the study began, that they may withdraw at any time during the study.

Participants begin by completing the Body Perception Questionnaire Short Form (BPQSF) (Porges, 1993, 2015) (Appendix 2). Participants then have the opportunity to wear the Oculus HMD (head mounted display) to make sure it is fitted comfortably and that they can clearly view their hands in the virtual environment. Participants' hands are augmented into the virtual environment via the leap motion controller, which uses infra-red tracking to create a detailed 3D representation of the hand (see Figure 1.1). Participants are then seated with their viewed hand resting on a black pillow adjacent to them at a height approximately 90cm above the floor (see Figure 2A).

Participants then begin either the Real Hand Illusion condition (ReHI), or the control condition. In the control condition, participants wear the HMD and view their hand being stroked by a paintbrush for 3 minutes. In this condition, there is a negligible instrinsic visual delay of <50ms which will not affect congruency of visuo-tactile information. In the illusory condition, participants once again view their hand being stroked by a paintbrush, but with a ~400ms visual delay to disrupt visuo-tactile information. Both the control and illusory conditions are completed in a randomised order across the left and right hand. After each of the four conditions, the participants will answer a 10 question 10 banded Visual Analogue Scale (VAS) (Appendix 4) in which participants will report their perceived ownership of their own hand and perceived embodiment of their hand's virtual representation. See Figure 3 for a flow guide to the protocol.

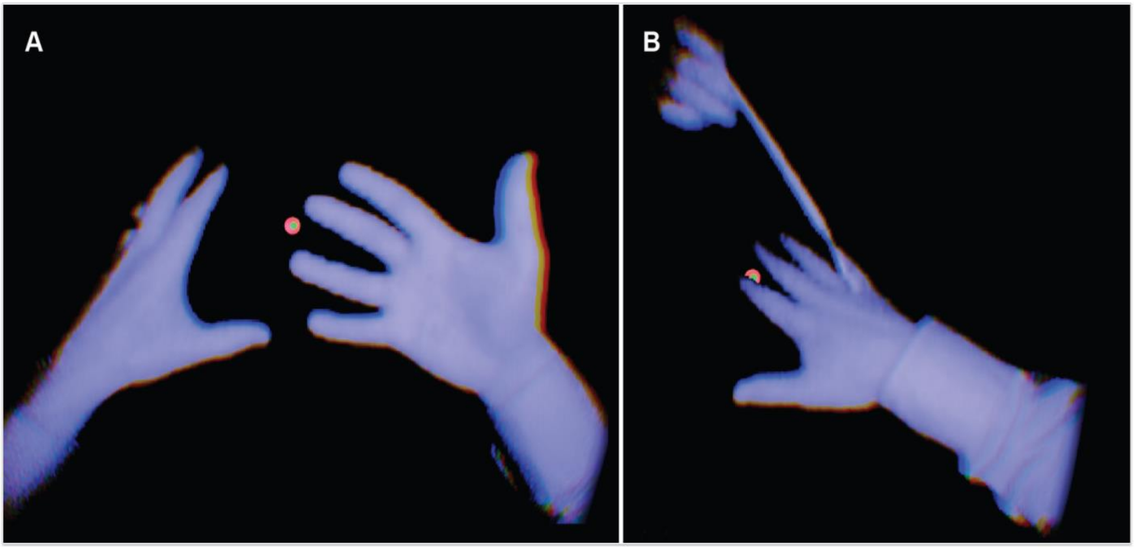


Figure 1.1 – A) Participant views a 3D representation of their hands in the virtual environment. B) Participant observes their right hand being stroked by a paintbrush in the virtual environment.

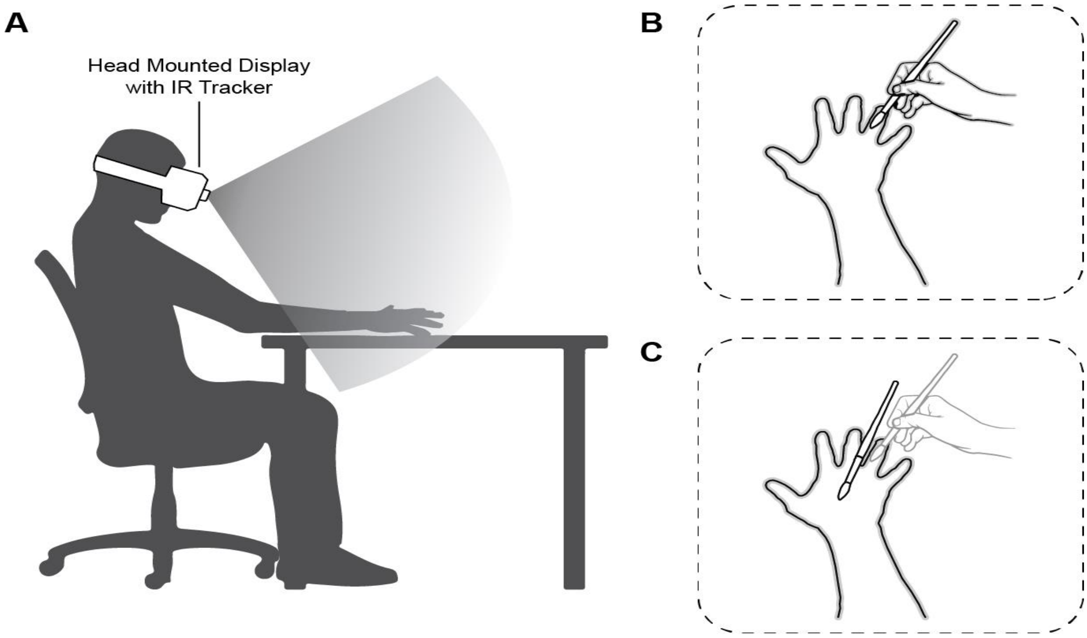


Figure 1.2 – A) Illustration depicts participant resting their hand on adjacent table whilst viewing their hand in the virtual environment. B) Control condition – Participant views their virtual hand being synchronously stroked by a paintbrush. C) Illusory condition – Participant views their virtual hand being asynchronously stroked by a paintbrush, with visual information being relayed with a 400ms delay.

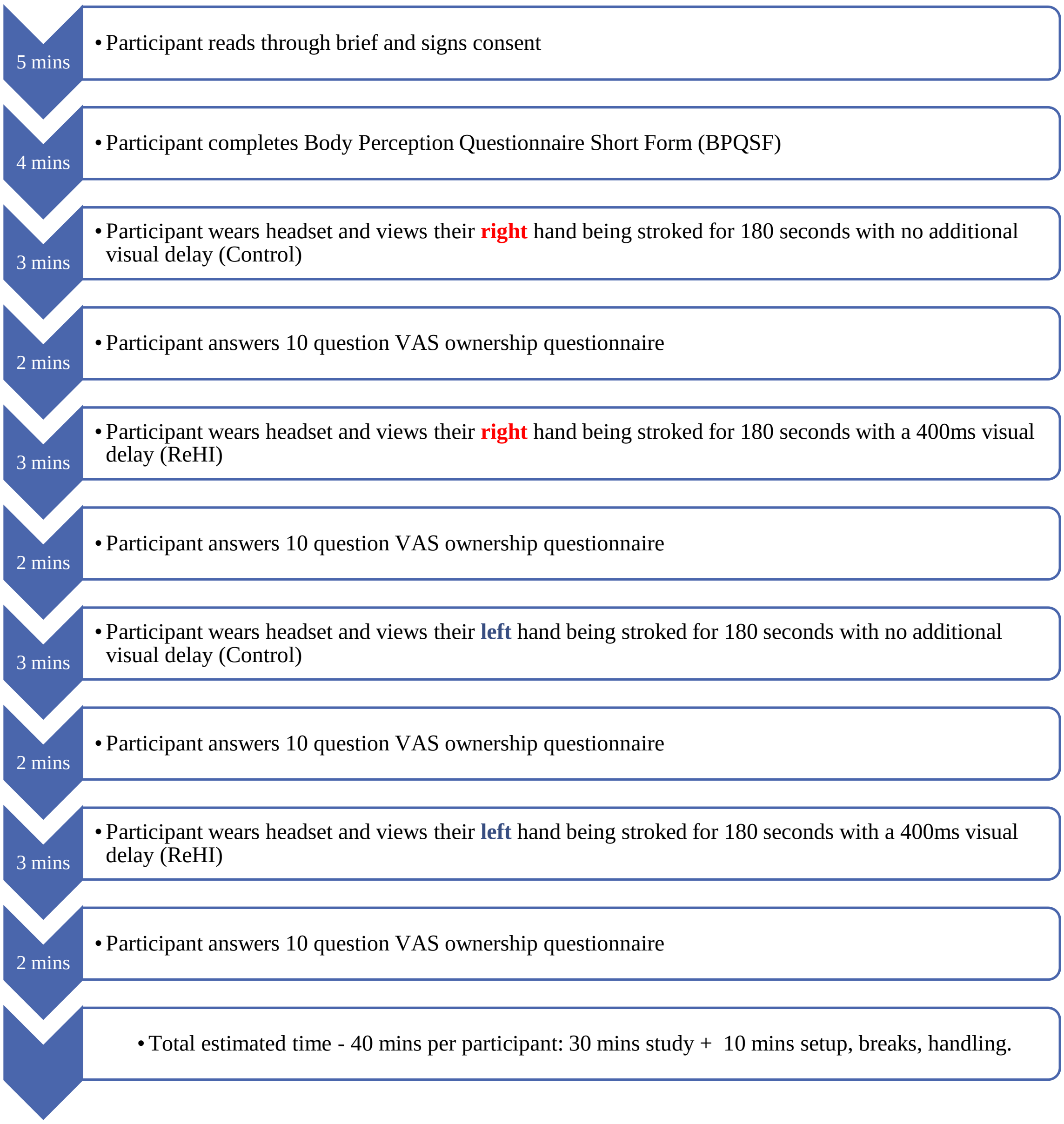


Figure 1.3 – Typical protocol and estimated task times of the behavioural study

Study 2 (Neurostimulation)

Participants

A previous rubber hand illusion which used rTMS neurostimulation of the left IPL in the RHI was used to calculate the effect size (Kammers et al, 2009). rTMS of the inferior parietal lobe had attenuated RHI scores in 14 participants with a Cohen's *d* of 2.140. Therefore, with an $\alpha = 0.05$ and a power of 95%, only 6 participants would be required. However, due to tDCS having a different and a likely less efficacious mechanism of action, we opted for a more conservative

Cohen's *d* of 0.75, which is still considered to be a strong *d* value when designing a tDCS study (Minarik et al., 2016). A Cohen's *d* required 26 participants, all of which were students at the University of Central Lancashire were recruited for the study via opportunity and volunteer sampling. 16 males and 10 females participated with a mean age of 21.32 (SD = 8.31). Participants were required to be over 18, right handed, are able to see in stereoscopic 3D. Participants were informed before the study that they would be compensated with an Amazon voucher to the value of £10 upon completion of both testing sessions. To prevent adverse events resulting from using the virtual reality headset and tDCS, a screening questionnaire was included in the participant briefing (see Appendix 5).

Ethical Approval

This study was approved by the University of Central Lancashire's Ethical committee (Unique code: PSYSOC336).

Montage parameters

Participants were then fitted with both the anodal and cathodal electrode for tDCS stimulation. It has been shown that the superior parietal lobe is located in the P4 region in the international 10-20 system (Herwig, Satrapi & Schönfeldt-Lecuona, 2003). Additionally, previous studies have used the P4 site to stimulate the superior parietal lobe (Ono, Mikami, Fukuyama & Mima, 2015).

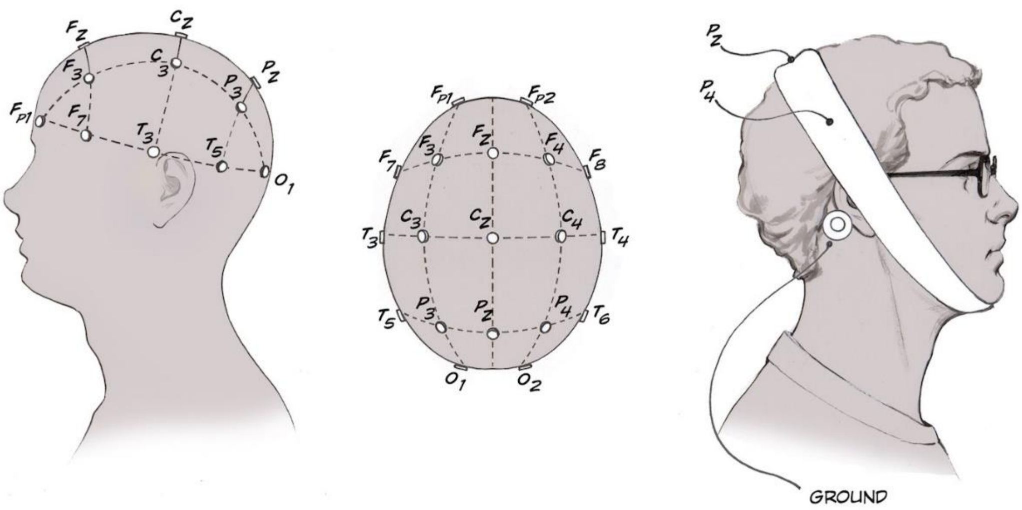


Figure 1.4 – Electrode locations of International 10-20 system for EEG and relative location of the P4 electrode (Backyardbrains, 2016)

Therefore, with the use of a 10-20 EASYCAP EEG cap for brain region mapping, participants had a saline soaked 6x5cm sponge electrode placed on the P4 site and on the ipsilateral shoulder. The electrodes were fastened firmly with a rubber belt strap to prevent movement during stimulation. In Cathodal and Anodal conditions, a current of 1.5mA (0.050mA/cm^2) was delivered for 20 minutes. This included 8 seconds of ramping up and 8 seconds of ramping down. The sham condition was subject to a predetermined schedule which is standard to the neuroConn DC-Stimulator PLUS device. This meant the current was initially ramped up (8s) to 1.5mA for 39 seconds (to simulate the feeling of stimulation) before dropping to a negligible level (Amp pulses of 115mA over 15ms) for the remainder of the session to maintain impedance checks. Of the 20 minutes of stimulation, the first 10 were a 'pre-stim' period, in which participants remained idle. The behavioural segment began once the 10 minutes of 'pre-stim' had concluded. The study was double-blinded to prevent any researcher or participant bias. This was achieved by using 5-digit codes which coded for either sham, anodal or cathodal stimulation. These codes were provided by the neuroConn DC-Stimulator PLUS device manual and were randomly assigned to participants prior to the beginning of the study.

Protocol

Participants were greeted upon arrival and were told what the aims of the study were and what was required of them. They were then given a briefing (Appendix 5) which gave further information regarding the protocol of the study. Participants then completed the screening questionnaire (related to VR risks) and had the opportunity to give written consent. Participants were reminded before the study began, that they may withdraw at any time during the study.

Participants then have the opportunity to wear the Oculus HMD (head mounted display) to make sure it is fitted comfortably and that they can clearly view their hands in the virtual environment. Participants' hands are augmented into the virtual environment via the leap motion controller, which uses infra-red tracking to create a detailed 3D representation of the hand (see Figure 1).

Participants are then seated with their viewed hand resting on a black pillow adjacent to them at a height approximately 90cm above the floor (see Figure 2A).

Participants then begin one of two sessions (the second of which is completed at least 3 days afterwards. In one session, they will have an active (e.g. cathodal) stimulation session, with the other day having both an active (e.g. anodal) and sham stimulation session. Therefore, there are four possible orders in which participants may complete the study, these are shown in table 1 below.

Table 1.1 – Four different orders of Neurostimulation study which are counterbalanced throughout the participant cohort.

Order	First Session	Second Session
1	Sham + Anodal	Cathodal
2	Sham + Cathodal	Anodal
3	Anodal	Sham + Cathodal
4	Cathodal	Sham + Anodal

Each session (anodal/cathodal/sham) was followed by the behavioural protocol on the left hand. After the 10 minutes of 'pre-stim', the participants underwent both the ReHI and the control task as well as completing the subsequent Body Ownership questionnaire. A typical order of events for both days of the Neurostimulation study can be found on the following page in figures 1.5 and 1.6.

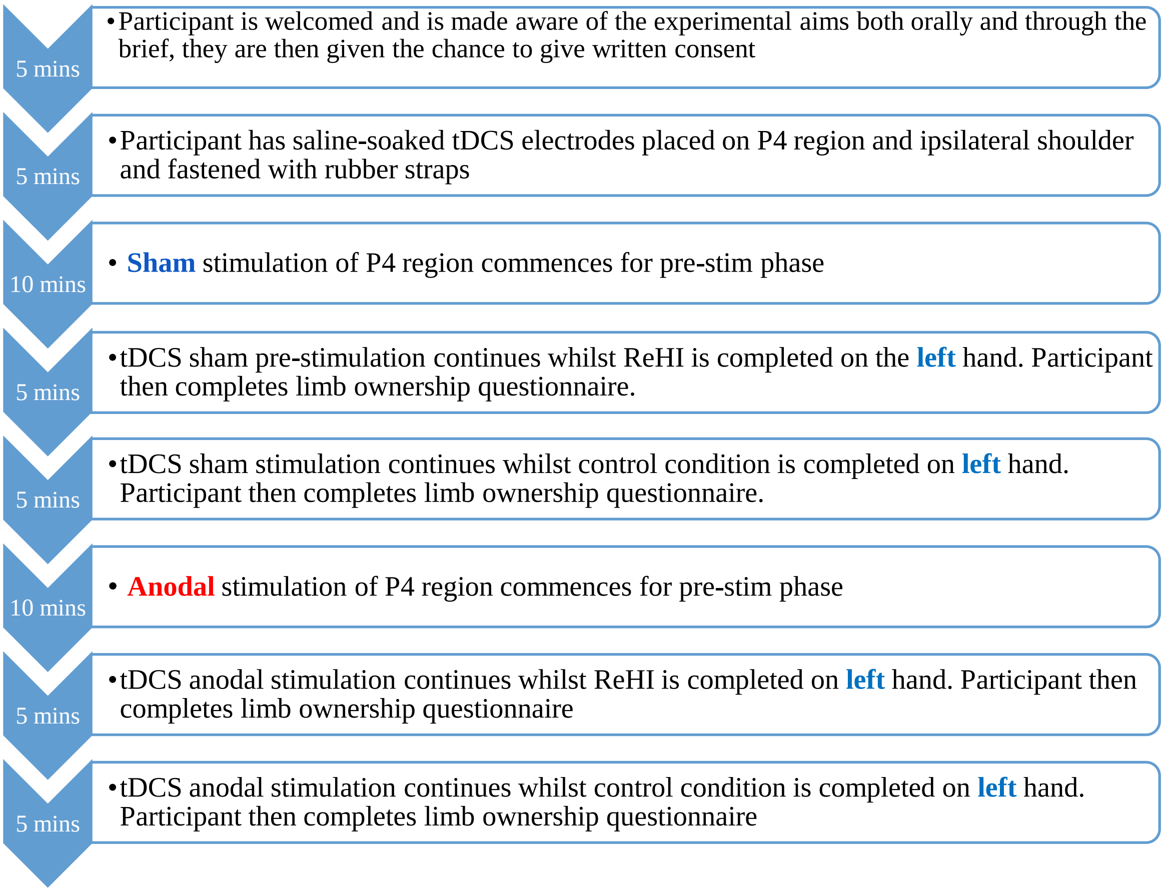


Figure 1.5 – Typical first neurostimulation session protocol and estimated task times. This session includes both sham and anodal stimulation of P4 region with subsequent behavioural conditions.

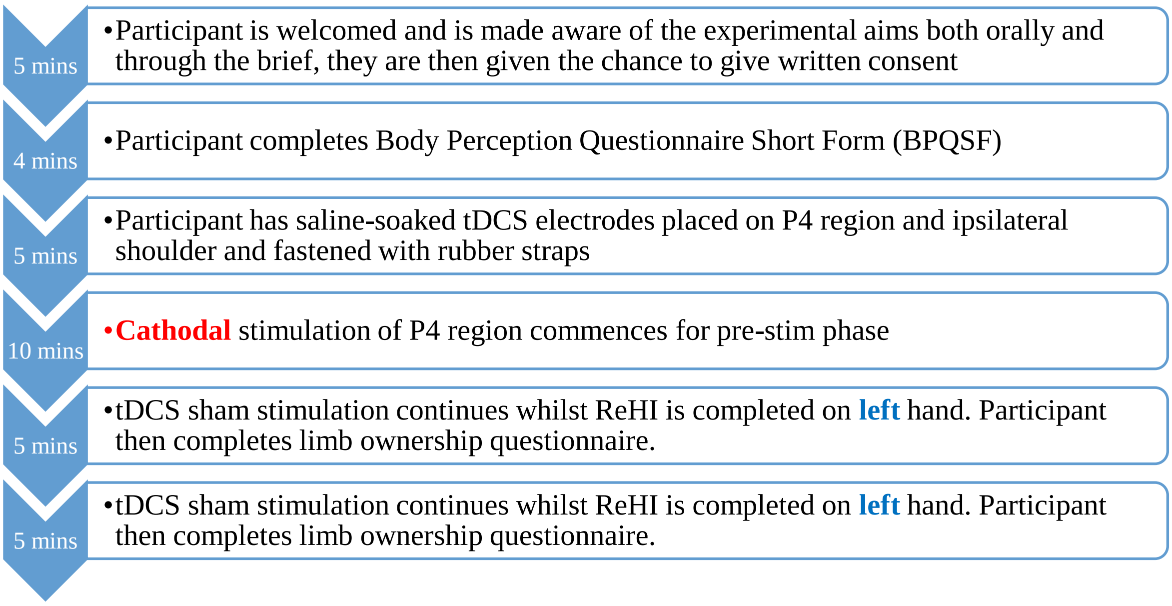


Figure 1.6 – Typical second neurostimulation session protocol and estimated task times. This session includes only cathodal stimulation of P4 region with subsequent behavioural conditions.

Equipment and Materials

Behavioural Study materials

A briefing document (Appendix 1) was given to participants at the beginning of the behavioural study. The document gave information about the general topic area, as well as a brief overview of the experimental protocol. The brief also contained a screening questionnaire, which prevented participants from taking part if they were deemed to be at risk when using the virtual reality HMD. The brief concluded with an opportunity for participants to sign written consent.

Participants completed the Body Perception Questionnaire Short Form in the behavioural study (Appendix 2) (BPQSF) (Porges, 1993, 2015). The first 20 questions of this questionnaire were used to record the participants' perceived awareness of internal bodily functions such as sweating or digestion.

A novel questionnaire (Table 1.2) was generated by the researcher which was adapted from the original Rubber Hand Illusion Questionnaire (Botvinick & Cohen, 1998) and subsequent RHI and VR studies (Longo et al., 2008, Ma & Hommel., 2015). The questionnaire measured the participants' perceived sense of ownership of their actual hand, as well as their perceived embodiment of the virtual hand. Participants were asked to rate each question based on when they felt the sensation was most vivid. This questionnaire was used in both the behavioural and neurostimulation studies.

Table 1.2 – The 10 items of the VAS body ownership questionnaire generated by the researchers, questions in italics had scores reversed.

1	I felt as though the virtual hand was my own
2	It felt as if the stroking I felt on my hand was due to the virtual object I saw stroking the virtual hand
3	I felt as though the stroking I felt on my hand was on the same location as where the hand was stroked
4	It seemed like the virtual hand resembled my own hand in terms of its shape and structure
5	I felt as though I could have moved the virtual hand like my own hand if I wanted
6	It felt as though I was looking at my own hand
7	*I felt as though I was looking at another person's hand*
8	*I felt as though I couldn't tell where my hand was*
9	*I felt as though my hand had disappeared*
10	*It felt as though the experience of my hand was less vivid than normal*

A debrief (Appendix 3) was provided at the end of the behavioural study which further explained the rationale for the study and gave contact details.

Neurostimulation Study Materials

For the Neurostimulation study, transcranial direct-current stimulation was provided by a neuroConn DC-Stimulator PLUS, serial number 1562 (neruoConn GmBH, 98693 Ilmenau, Germany). The P4 region was located using an EASYCAP 21 electrode EEG cap (EASYCAP, DE-82211 Herrsching).

A briefing document (Appendix 5) was given to participants at the beginning of the neurostimulation study. The document gave information about the general topic area, as well as a brief overview of the experimental protocol. The brief also contained a screening questionnaire, which prevented participants from taking part if they were deemed to be at risk when using the virtual reality HMD or the tDCS. The brief concluded with an opportunity for participants to sign written consent.

A debrief (Appendix 6) was provided at the end of the neurostimulation study which further explained the rationale for the study and gave contact details.

Visual Stimuli

Participants used the Oculus Rift as the HMD (Oculus Rift DK2) (Subsidiary of Facebook, Menlo Park, CA, USA) Version 1.6 (SDK 0.5.0.1). The headset has a resolution of 960x1080 in each lens with a horizontal field of view of 100°, and had a variable refresh rate of up to 60Hz.

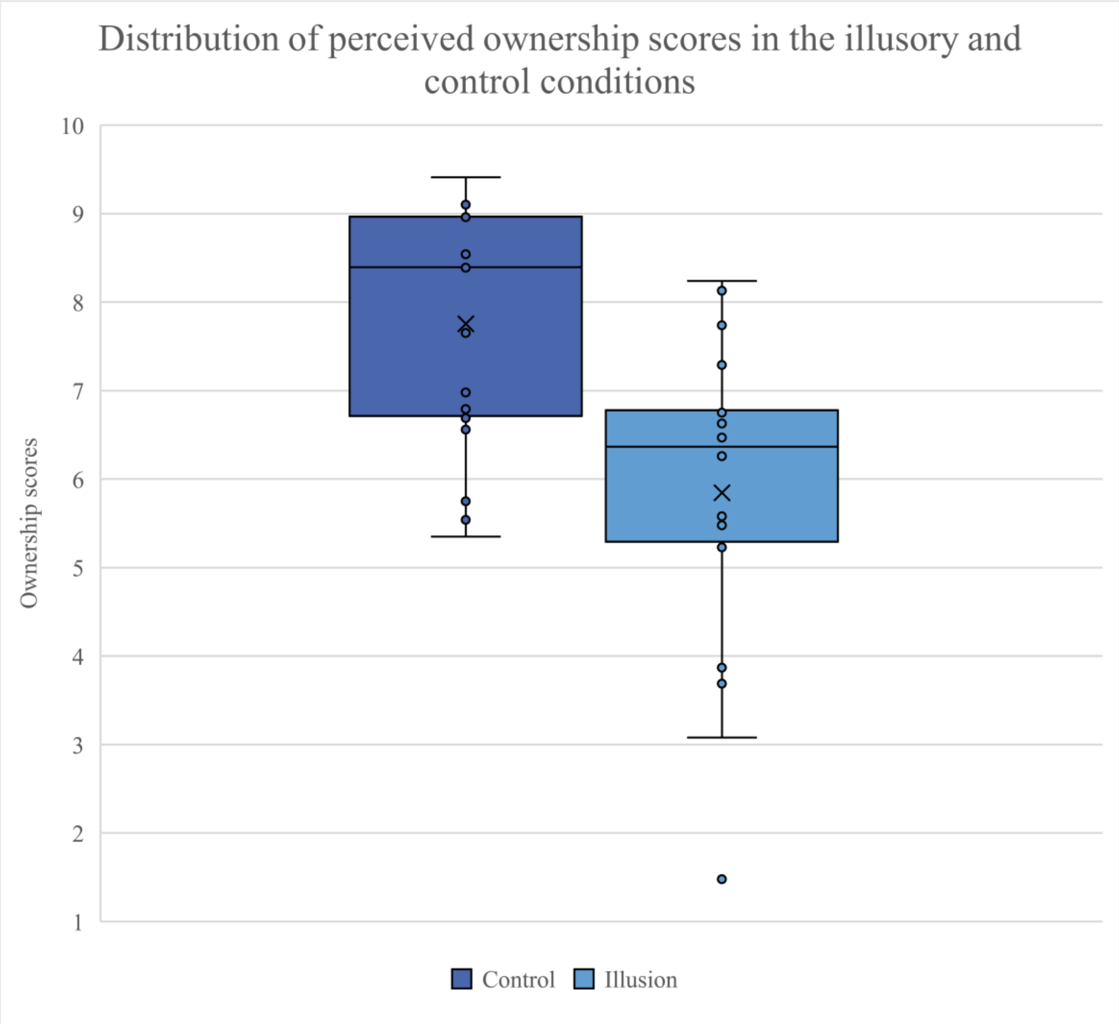
To track the participants' hand movements, an infra-red sensor (leap motion) was used: (Leap Motion, Inc. San Francisco, CA, USA) Software Version 2.3.1. This augmented the immediate environment around the participant into the virtual space, the participants' hands were placed on a nonreflective material so that only the hand could be seen.

The HMD was connected to a MacBook Pro (Apple Inc, Cupertino, CA, USA) Retina, 15-inch, Mid 2015, AMD Radeon R9 M370X. Finally, the program within the laptop used to create the real hand illusion paradigm and the agency task was 'Unity' (version 5.1.x) (Unity Technologies, San Francisco, CA, USA Version 5.1.3f). Unity was used to create a 40-frame delay in order to produce a ~400ms delay. This includes the natural latency of the equipment which is as follows, tracking camera frame rate (120fps, ~8ms), tracking algorithm (4ms), display refresh rate (60Hz, ~17ms), and GPU calculations (~17ms) with a total latency of ~46ms as calculated by Bernal, Maes & Kannape (2016).

RESULTS

Pilot study

A pilot study of the behavioural paradigm (N=20, age=21±1 years, 8 male & 12 females) was conducted to assess the illusory strength of the virtual paradigm. Participants' scores were established using the mean of the 10 questions. A t-test was used to compare the synchronous stroking condition with the asynchronous condition and subsequently revealed a highly significant effect ($t(19)=4.58, p<0.001$, Cohen's dz = 1.02). Mean questionnaire scores decreased from 77.5 ± 13.1 in the synchronous condition to 58.5 ± 17.3 in the ReHI.



Graph 1.1 – Mean values (x), interquartile range (main boxes) and distribution of ownership questionnaire scores (o) across the illusory and control conditions. Whisker bars denote minimum and maximum scores.

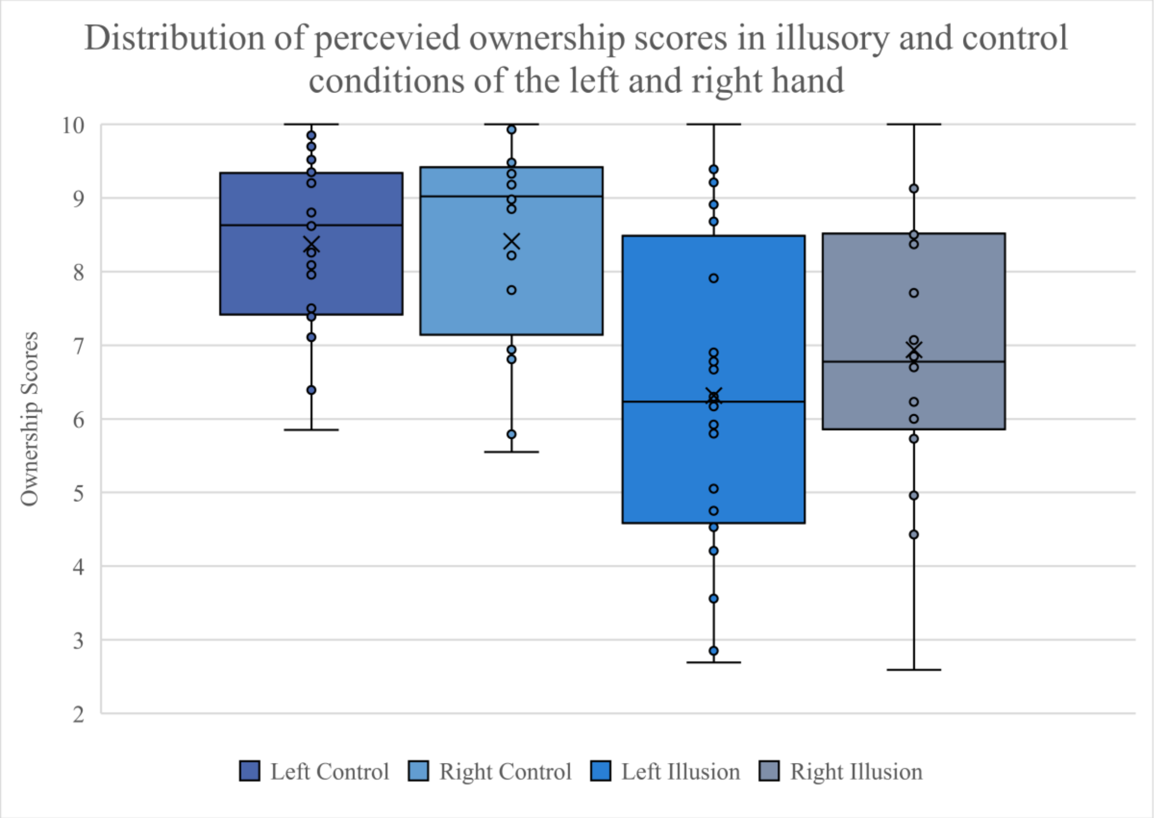
Study 1 – Behavioural results

Real hand illusion and hand laterality

A 2-way repeated measures ANOVA was run to investigate whether hand ownership questionnaire scores were affected by the ReHI and hand laterality. A main effect for ReHI was found, indicating that the ReHI significantly affected hand ownership questionnaire scores compared to the control condition: $F(1,19) = 16.04$, $p = .001$. There was no main effect found for hand laterality in hand ownership questionnaire scores: $F(1,19) = 2.86$, $p = .107$. A significant interaction was found between the ReHI and hand laterality: $F(1,19) = 5.84$, $p = .026$.

Table 2.1 – Ownership questionnaire mean scores and standard deviations across the illusory and control conditions in the left and right hand.

Left Control		Left ReHI		Right Control		Right ReHI	
Mean	SD	Mean	Sd	Mean	Sd	Mean	SD
83.78	11.77	63.16	21.99	84.13	14.62	69.56	17.91



Graph 1.2 - Mean values (x), interquartile ranges (main boxes) and distribution (o) of ownership questionnaire scores across the illusory and control conditions in the left and right hand. Whisker bars denote minimum and maximum scores.

Study 1 post hoc t-tests

Main effect of illusion t-tests

Post hoc pairwise comparisons were made to reveal whether the main effect of illusion was present in both the left and the right hand. Firstly, questionnaire scores in the left control condition (83.78 ± 11.77) were significantly higher than the left ReHI condition (63.16 ± 21.99): $t(19) = 4.14$, $p = .001$. Secondly, questionnaire scores in the right control condition (84.13 ± 14.62) were significantly higher than the right ReHI condition (69.56 ± 17.91): $t(19) = 3.53$, $p = .002$. Both t-tests were significant to a Bonferroni correction of .025.

Interaction between ReHI and hand laterality t-tests

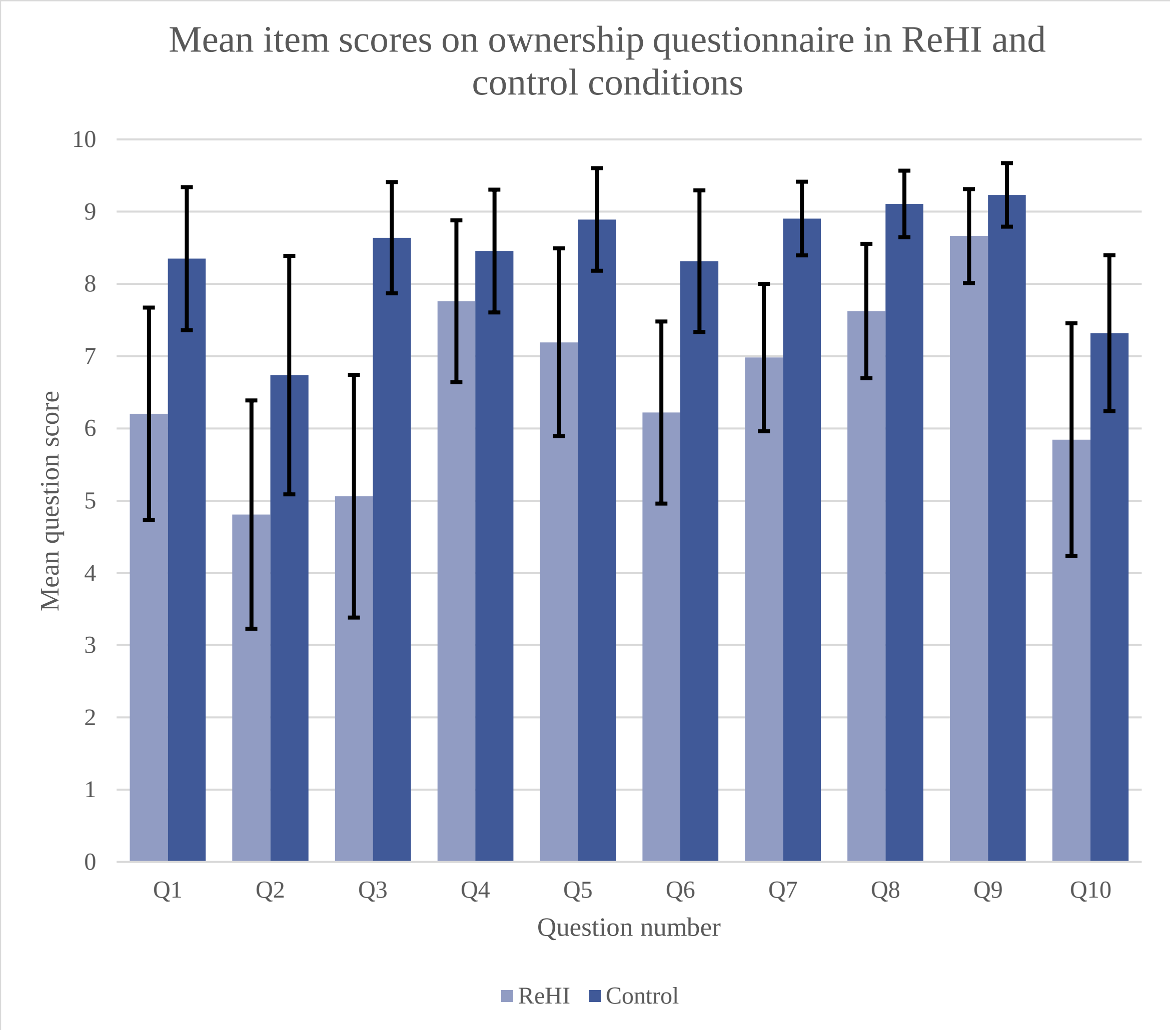
Post hoc t-tests were also used to reveal where the variance between hand laterality and effect of illusion was. There was no significant differences between questionnaire scores in the right control condition (84.13 ± 14.62) compared to the left control condition (83.78 ± 11.77): $t(19) = .76$, $p = .863$ However, right ReHI questionnaire scores (69.56 ± 17.91) were significantly higher than left ReHI scores (63.16 ± 21.99): $t(19) = 2.38$, $p = .028$.

Analysis of individual ownership questionnaire items in ReHI and control conditions

The hand ownership questionnaire was further analysed to reveal which questions had scores deviate significantly from the control to the ReHI condition. Table 2.2 displays the results of pairwise t-tests between question scores in both conditions across both left and right hands. Questions 1, 2, 3 & 6) were all significant, indicating feelings of ownership decreased in the illusory condition. Question, 5 also significantly decreased in the illusory condition, indicating a decrease in feelings of agency in the biological hand. Question 8 significantly increased in the illusory condition, indicating participants felt greater *dis*ownership of their biological hand. Finally, question 4 acted as a control question, it showed no significant change in scores between the two conditions.

Table 2.2 Mean scores, standard deviations and levels of significance of each item in the hand ownership questionnaire

Question	Control mean	Control Standard Deviation	ReHI mean	ReHI Standard Deviation	Level of significance at a 2-tailed level *denotes sig below .05 ** denotes sig below .01 NS denotes non-significant results
I felt as though the virtual hand was my own	**8.35**	1.98	**6.20**	2.94	**
It felt as if the stroking I felt on my hand was due to the virtual object I saw stroking the virtual hand.	**6.74**	3.34	**4.81**	3.06	*
I felt as though the stroking I felt on my hand was on the same location as where the virtual hand was stroked.	**8.64**	1.54	**5.06**	3.34	**
It seemed like the virtual hand resembled my own hand in terms of its shape and structure.	**8.46**	1.70	**7.76**	2.24	NS
I felt as though I could have moved the virtual hand like my own hand if I wanted.	**8.89**	1.42	**7.19**	2.61	*
It felt as though I was looking at my own hand.	**8.32**	1.96	**6.22**	2.53	**
I felt as though I was looking at another person's hand.	**8.91**	1.03	**6.98**	2.05	**
It felt as though I couldn't tell where my hand was.	**9.11**	0.93	**7.63**	1.86	**
I felt as though my hand had disappeared.	**9.23**	0.88	**8.66**	1.29	NS
It felt as though the experience of my hand was less vivid than normal.	**7.32**	2.16	**5.85**	3.23	NS



Graph 1.3 – Mean item scores of the ownership questionnaire of both ReHI and control conditions, error bars indicate one standard deviation

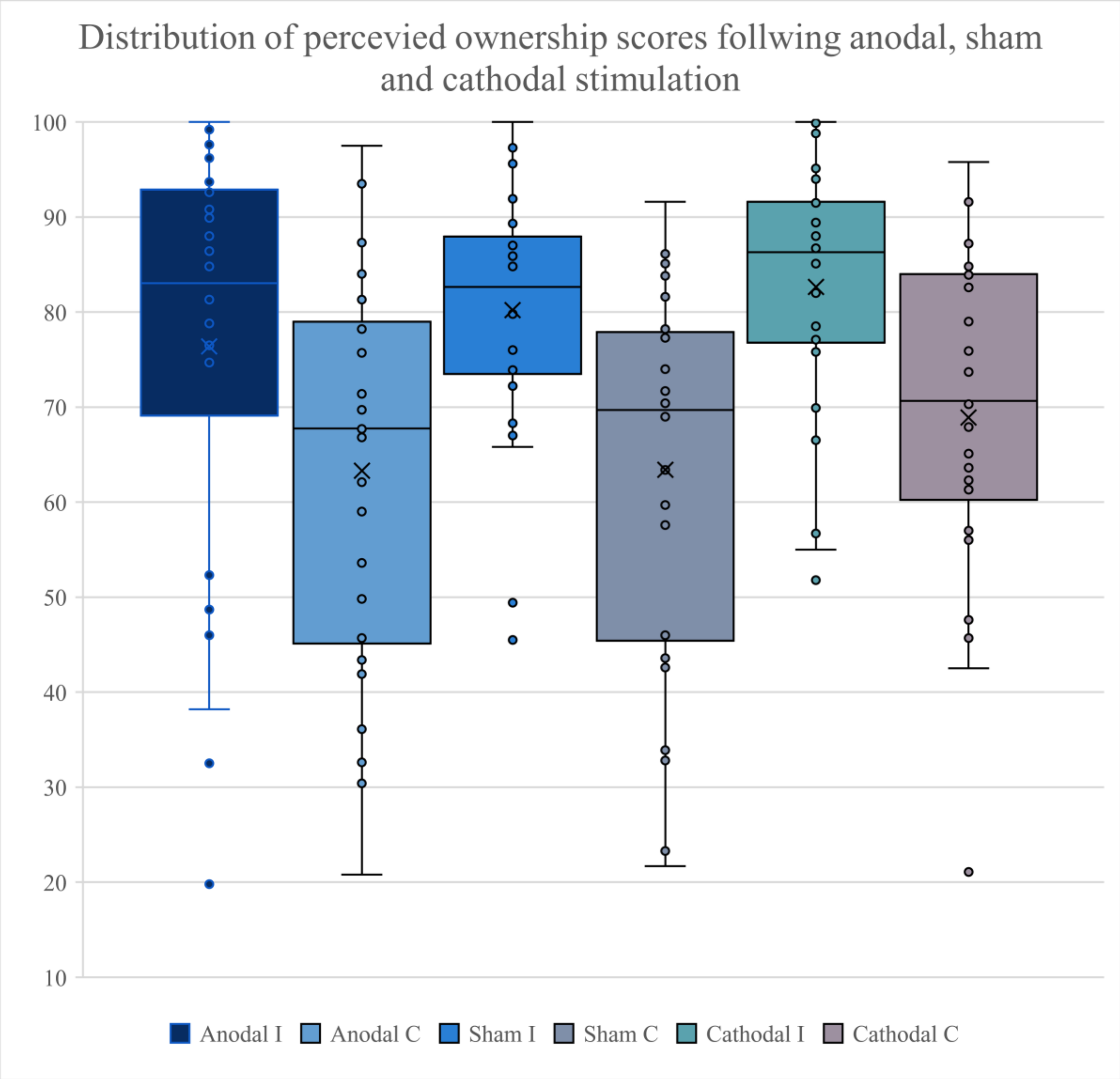
Perceived interoceptive awareness as a predictor of ReHI illusory strength

One of the studies research aims was to investigate whether participants' *perceived* interoceptive awareness was a predictor of hand ownership malleability, as measured by their illusory strength scores i.e. the difference between individuals' control and ReHI scores. A simple linear regression was used to calculate whether perceived interoceptive awareness predicted illusory strength of the ReHI. A non-significant result was found ($F(1,18) = .089$, $p = .769$, with an R^2 of .005.

Study 2 – Neurostimulation results

Real Hand Illusion and tDCS Anodal/Cathodal/Sham stimulation

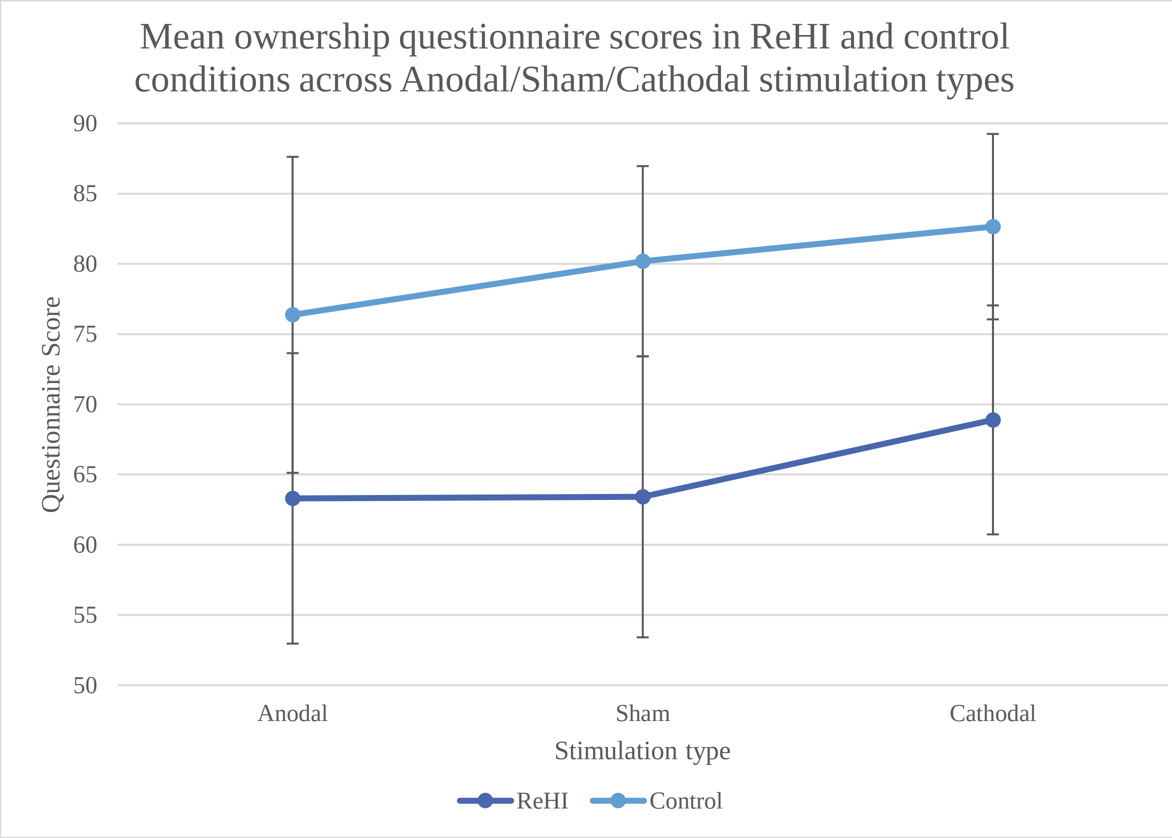
A repeated measure 2x3 ANOVA was conducted to assess variance in questionnaire scores across the two independent variables, ReHI and stimulation type. A main effect was found again for ReHI, indicating the illusory condition reduced feelings of ownership: $F(1,25) = 30.24$, $p < .001$. A main effect was also found for stim type, indicating tDCS had an effect on perceived ownership: $F(2,50) = 3.52$, $p = .037$. There was no significant interaction between stimulation type and ReHI: $F(2,50) = .41$, $p = .664$.



Graph 1.4 - Mean values (x), interquartile ranges (main boxes) and distribution of ownership scores in ReHI and control conditions across Anodal/Sham/Cathodal stimulation types. Whisker bars denote maximum and minimum scores.

Table 2.1 – Ownership questionnaire mean scores and standard deviations across the illusory and control conditions across anodal/sham/cathodal conditions

	Anodal ReHI	Anodal Control	Sham ReHI	Sham Control	Cathodal ReHI	Cathodal Control
Mean	63.30	76.37	63.41	80.19	68.89	82.65
SD	20.69	22.51	20.02	13.44	17.18	13.25



Graph 1.5 – Mean values of ownership scores in the ReHI and control conditions across Anodal/Sham/Cathodal conditions, error bars indicate one standard deviation

Study 2 post hoc t-tests

Main effect of illusion post hoc t-tests

Post hoc pairwise comparisons were conducted to see whether there was a main effect of illusion for all three stimulation conditions. The anodal control condition (μ = 76.37 ± 22.51) had significantly higher questionnaire scores than the anodal ReHI condition (μ = 63.30 ± 20.69): $t(25) = 3.41$, $p = .002$. The sham control condition (μ = 80.19 ± 13.44) had significantly higher questionnaire scores than the sham ReHI condition (μ = 63.41 ± 20.02): $t(25) = 4.64$, $p < .001$. The cathodal control condition (μ = 82.65 ± 13.25) had significantly higher questionnaire scores than the cathodal ReHI condition ($\mu = 68.89 \pm 17.18$): $t(25) = 3.96$, $p < .001$. All three t-tests were significant to a Bonferroni correction of 0.017.

Main effect of stimulation post hoc t-tests

Secondly, post hoc tests were carried out to investigate the variance in questionnaire scores regarding the main effect of tDCS. The cathodal conditions ($\mu = 75.77 \pm 12.52$) had significantly higher questionnaire scores than the anodal conditions ($\mu = 69.83 \pm 19.28$): $t(25) = 2.31$, $p = .029$. No other tests were conducted as this was the only likely candidate for a significant result.

Reliability test of ownership questionnaire – Cronbach's Alpha

A reliability test was conducted to establish how reliable the items of the ownership questionnaire were, results from the left-handed control conditions in study 1 and the sham control condition in study 2 were used ($N = 46$). The questionnaire was found to be reliable: (10 items) $\alpha = .79$.

A second reliability test was conducted to establish whether the items of the ownership questionnaire were also reliable across the illusory conditions. Results from the left-handed ReHI conditions in study 1 and the ReHI control condition in study2 were used ($N = 46$). The questionnaire (10 items) was found to be highly reliable $\alpha = .88$.

DISCUSSION

Interest in the RHI over the past two decades has revealed much about how the malleability of body ownership allows mislocalisation of limbs to extrabodily objects. Botvinick & Cohen (1998) initially claimed that the effects of the RHI were due to individuals resolving conflict between disparate visual and somatosensory information. Subsequent research has revealed a more complex process, where ownership is driven by the congruency of exteroceptive, proprioceptive, interoceptive information (Tsakiris, 2010). Further to this, it appears that top-down processing of physical corporeality is necessary for a phenomenological experience of ownership (Tsakiris, 2010). The current literature has mostly focused on how embodiment of foreign objects can arise through perceptual illusions. This however, may not be representative of disorders where disownership of one's biological limb arises, rather than misattribution of foreign limbs. One of the main purposes of the research was to develop a novel paradigm which more closely replicates the phenomenology of disorders such as Xenomelia. It is thought that feelings of disownership in Xenomelia may result from incorrect processing of visuo-tactile information (Lenggenhager, Hilti & Brugger, 2015).

ReHI reduces feelings of ownership in the biological limb

Consequently, the ReHI created a discrepancy between visual and tactile feedback in an attempt to create an illusory condition which represented sensations of disownership in the biological hand. This was demonstrated initially in the illusory condition of the pilot study, in which the participant perceives visual feedback of seen brush stroke 400ms after the felt sensation. A comparison of ownership scores showed a significant decrease in perceived ownership in the ReHI compared to the control condition. This effect was replicated in study 1, across both hands, where the data revealed a highly significant main effect of the ReHI on ownership scores. This suggests that delays in visual feedback had a direct effect decreasing feelings of ownership in the participants' biological hand. Further analysis of individual questions in the questionnaire revealed that ownership of the virtual hand was systemically lowered in the ReHI as measured by the question "I felt as though the virtual hand was my own". Additionally, sense of agency of the virtual hand was also reduced in the ReHI, as measured by "I felt as though I could have moved the virtual hand like own hand if I wanted". Conversely, disownership of the biological hand, as measured by "I felt as though I was looking at another person's hand" was systematically increased in the ReHI. Participants commonly reported that the ReHI condition as a bizarre feeling which was often uncomfortable and had a direct effect in making the brush stroke feel more 'ticklish'. Encouragingly, these reports and the significant decreases in ownership appear to loosely reflect the phenomenology of disorders such as Xenomelia. Based on these findings, it is evident that we have successfully and systematically reduced feelings of ownership and increase feelings of disownership in the biological hand by means of disrupting the process of real-time visuo-tactile integration.

Effect of hand laterality in the ReHI

Study 1 also sought to investigate whether hand laterality was a factor in the ReHI. This stems partly from disorders with body ownership deficits such as Xenomelia (Hilti et al, 2012) and Somatoparaphrenia (Vallar & Ronchi, 2008), where body disturbances have a higher incidence in left sided limbs. Furthermore, laterality studies of the RHI have shown that implicit ownership of the rubber hand is more strongly invoked in the left hand (Ocklenburg, Rüther, Peterburs, Pinnow & Güntürkün, 2011). Therefore, it may be that individuals have stronger bodily representations of their right sided limbs. The data revealed no main effect of hand laterality in hand ownership scores. However, an interaction between hand laterality and the ReHI was found. Post hoc analysis revealed that there was no difference between the right and left and control conditions, but revealed a difference between the right and left ReHI conditions. It appears that the left hand ReHI significantly deviated more from the control conditions than the right hand. Initially, this suggests that ownership of the left hand may be more malleable than the right. Furthermore, it could be argued that perhaps left sided limbs are less resilient to disturbances in cross-modal input from visual and somatosensory modalities than their right sided counterparts. One obvious issue with speculating as to why left sided limbs were more sensitive to the ReHI is that all participants were right handed. It could therefore be the case that participants experienced increased feelings of disownership in left sided limbs due to a natural contralateral dominance. Therefore, a left-handed cohort would be required to see whether the result is a genuine characteristic of body malleability. Despite this, previous studies had shown that handedness has no effect on the vividness of the RHI (Ocklenburg, Rüther, Peterburs, Pinnow & Güntürkün, 2011). This does however, appear to reflect the first time that ownership disturbances have been evoked more strongly in left sided limbs as measured phenomenologically and not through implicit measures such as skin conductance responses. If not due to handedness, there may be other possible explanations. There is an argument that it may be due to the paradigm's altered mechanism of action from the RHI, whereas the RHI appears to generate embodiment of the rubber hand by resolving multisensory conflict, the ReHI systematically increases disownership of the biological hand by disturbing the integration of the multisensory feedback. As the illusion is now directly targeting the biological limb, coupled with the increased proprioceptive accuracy (a rubber hand only ever occupied the peripersonal space), the illusion may now be more vivid and may more accurately reflect the phenomenology of disorders such as Xenomelia. This may allow for greater sensitivity in detecting laterality differences in limb malleability through perceptual illusions. Furthermore, if individuals have a naturally occurring right sided dominance for bodily representations, it may explain why left sided limbs have a higher propensity for feelings of disownership.

Interoceptive awareness as a predictor of illusory strength

There has been previous research which has suggested that interoceptive awareness may be a predictor of illusory strength in the RHI (Tsakiris, Jimenez & Costantini, 2011). That is to say, low interoceptive awareness predicts greater illusory effects in the RHI. It is thought this may be due to greater attentional resources being available for exteroceptive processing. Alternatively, it may be that higher interoceptive awareness allows for a greater efficiency in processing body perceptive signals by co-weighting interoceptive and exteroceptive information (Tsakiris, Jimenez & Costantini, 2011). Based on the study, we predicted that participants with low interoceptive awareness (as measured by a self-report questionnaire) would experience greater changes in ownership in the ReHI. A simple linear regression revealed that there was no relationship between interoceptive awareness and illusory strength. One possible explanation that there was no relationship found was due to how interoceptive awareness was recorded. We opted to use items related to interoceptive awareness from the Body Perception Questionnaire Short Form (BPQSF) (Porges, 1993, 2015, Appendix 2). However, these questions are related specifically to participants' perceived interoceptive awareness rather than their accuracy. The significance of this is that perceived accuracy and actual accuracy of interoceptive awareness have shown to be dissociable traits (Garfinkel, Seth, Barrett, Suzuki & Critchley, 2015). It is therefore possible that this has given rise to a false negative, future iterations of the ReHI should use an alternative measure such as the 'heartbeat tracker' task to measure interoceptive accuracy (Knapp-

Kline & Kline, 2005). Conversely, recent research has not been able to reproduce interoceptive awareness as a predictor of illusory strength (Crucianelli, Krahé, Jenkinson & Fotopoulou, 2017). This could be due to how cardioceptive ability is specifically recorded, with a recent study suggesting that the heartbeat tracker may not be a valid tool to measure interoception at all (Ring, Brener, Knapp & Mailloux, 2015). Arguably, the relationship between interoception and ownership arising from processing of multisensory information needs to be better established. This could be achieved through a more thorough series of interoceptive measures, which assess a combination of interoceptive abilities rather than just cardioceptive.

Study 2

ReHI and effects of tDCS

Study 2 aimed to establish the relationship between the right parietal lobe and the integration of multisensory information leading to feelings of ownership. The right SPL has been implicated in the processing of this information following imaging data of individuals with Xenomelia (McGeoch et al, 2011). Tactile stimulation of deafferent regions led to significantly reduced activation of the right SPL (McGeoch et al, 2011). Further to this, Lenggenhager, Hilti & Brugger (2015) have suggested that incorrect processing of multisensory information may cause feelings of disownership of limbs in individuals with Xenomelia. Therefore, we used both anodal and cathodal stimulation of the P4 region (according to the 10-20 system) during the ReHI and control conditions to see whether it would modulate feelings of ownership. A 2x3 repeated measure ANOVA revealed that a main effect of ReHI was once again achieved as in the pilot study and study 1. A main effect was also found for stimulation type, with cathodal stimulation attenuating feelings of ownership in the biological hand and with a reverse effect for anodal stimulation. Therefore, we were able to successfully modulate perceived ownership through electrical stimulation of the P4 region. The findings appear to further implicate right parietal regions as being responsible for the loss of ownership of limbs in individuals with Xenomelia.

The main effect of stimulation was however, the reverse to what our hypothesis predicted, as we had expected anodal stimulation to strengthen bodily representations. Therefore, we need to reevaluate how the right parietal region may be integrating the multisensory information. The mechanism of tDCS may explain how it modulates one's perceived body ownership in the virtual paradigm. tDCS acts by reducing or increasing the threshold at which depolarisation occurs (Nitsche, Boggio, Fregni & Pascual-Leone, 2009). The result of this is that spontaneous neural activity is either increased or decreased, depending on the current direction. By increasing spontaneous neural activity in the P4 region, participants experienced weaker feelings of ownership to the biological limb and vice versa for decreased spontaneous activity. It may be that the region seeks to detect discrepancies in visuo-tactile information before allowing the data to be integrated. If the region functions by identifying these incongruences, then a higher level of spontaneous activity may lower the threshold for the region to consider the two data streams as conflicting. Weaker bodily representations in anodal conditions may therefore be driven by the P4 region being more likely to consider two sets of sensory information as incongruent, subsequently leading to the modalities not being integrated. In cases of Xenomelia, it appears that region is not significantly activated following tactile stimulation (McGeoch et al, 2011). Therefore, it may be that afferent information is not even being considered by the region to be integrated, leading to feelings of disownership. Rather, it may lack the necessary cortical structures related to specific regions of the body model, leading to the right SPL to be non-responsive to body region specific sensory information. This may also explain why in cases of Xenomelia, there is usually a clear border as to where the participant feels ownership and where they do not.

Participant 14

One interesting result from the neurostimulation study were the ownership scores of participant 14 in the anodal and cathodal conditions. The participant showed no changes in hand ownership in the sham condition, but showed significant reverse effects in both neurostimulation conditions. That is to say, the participant reported significantly higher feelings of ownership in the ReHI condition compared to the control. It is not clear how this effect was achieved and it is difficult to speculate on the basis of a single participant. It should be noted for future ReHI studies which involve neurostimulation, that there may be a propensity for reverse effects of the ReHI.

Implications of the research

The main aim of the research was to produce a novel virtual reality paradigm which induces disownership of the biological hand and therefore replicates the phenomenology of Xenomelia. The virtual illusion appeared to successfully attenuate feelings of ownership in the biological hand, with participants consistently reporting the experience as uncomfortable, bizarre and ticklish. Due to Xenomelia being a rare disorder (Brugger et al, 2013), the paradigm appears to be a reliable and valid paradigm in which to replicate the symptoms of the disorder in healthy participants. This appears to be an improvement on existing paradigms such as the RHI, which cause embodiment of a foreign object, rather than systematically reducing ownership of one's own limb. Significantly, the ReHI paradigm therefore allows researchers to investigate how body disownership may arise in significantly larger participant groups than from clinical populations. Furthermore, by use of the virtual reality equipment, congruency of visual and tactile information can be highly controlled in comparison with the RHI. This can be achieved by making minor adjustments to the latency of visual feedback.

Moreover, the results of the laterality study revealed that the left hand succumbed to higher illusory effects in the ReHI than the right hand. Previously, RHI paradigms had shown only implicit measures of ownership to be affected by perceptual illusions (Ocklenburg, Rüther, Peterburs, Pinnow & Güntürkün, 2011). Crucially, this may be a phenomenon specific to the ReHI compared with classical paradigms. The results appear to be consistent with clinical cases where body disownership is more prevalent in left sided limbs (Hilti et al, 2012., Vallar & Ronchi, 2008). Therefore, the significance of the study is that it further implies weaker left sided bodily representations as being involved in the aetiology of body disturbances.

A further aim of the research was to investigate the link between right parietal regions and disownership of biological limbs in Xenomelia. tDCS was used as a tool to modulate spontaneous neural activity in the P4 region. Anodal conditions caused feelings of ownership of the biological hand to be significantly weaker than those in the cathodal condition. The significance of these results appears to suggest a causal link between multisensory integration in the P4 region and the phenomenological sensation of bodily ownership. Firstly, this reiterates the importance of the integration of congruent exteroceptive sensory data to drive feelings of body ownership. Secondly, it appears to support previous neuroimaging evidence which correlated reduced right SPL activity with strong feelings of disownership in the biological limb (McGeoch et al, 2011). Finally, the cathodal stimulation conditions resulted in higher feelings of perceived ownership. Therefore, repeated neurostimulation of the P4 region may provide therapeutic relief for individuals with Xenomelia.

Limitations and future improvements of the research

Despite an interaction between effects of stroking synchronicity and hand laterality being found in study 1, conclusions drawn from the results must be done cautiously. Laterality differences in ownership malleability may be due to handedness (all participants were right handed) resulting in stronger representations of the dominant hand. Future iterations of the ReHI should therefore involve both right and left handed participants to investigate whether laterality differences in explicit ownership are still reported.

As mentioned previously, it may be possible that perceived interoceptive awareness may not predict illusory strength as it is a dissociable trait from interoceptive accuracy (Garfinkel, Seth, Barrett, Suzuki & Critchley, 2015). The literature reports conflicting evidence on whether interoceptive abilities predict illusory strength (Tsakiris, Jimenez & Costantini, 2011., Crucianelli, Krahé, Jenkinson & Fotopoulou, 2017). Furthermore, it is even questionable whether the heartbeat tracker task is a valid tool in measuring interoceptive accuracy (Ring, Brener, Knapp & Mailloux, 2015). Therefore, future iterations of the ReHI should seek to utilise a more robust assessment of interoceptive accuracy to establish a link between the trait and susceptibility to limb disownership.

Despite the questionnaire showing highly significant changes in ownership, disownership and agency, further research must be completed to better understand the subjective components of the ReHI. A precedent for this approach has been set with Longo et al (2008), who used a cluster analysis of a 27-item questionnaire to better understand the subjective experience of the RHI. We recommend that future research take a psychometric approach to the ReHI to further reveal the phenomenological structure of illusory limb disownership. Furthermore, it may also provide a more detailed account of how the RHI subjectively differs from the ReHI.

We have suggested that differences in perceived ownership of the biological limb in the anodal and cathodal conditions are likely from changes in multisensory integration. However, it is clear that further research is needed to support this claim. Current research has suggested that the temporal limit of visual delay before individuals experience misattribution to a rubber hand is ~300ms (Costantini et al., 2016). Therefore, using the ability of VR to make minute changes in visual latency, a future use of the ReHI would be to use neurostimulation across illusory conditions with varied levels of delay. Anodal neurostimulation may act by lowering the threshold at which a stream of visual and tactile information is considered incongruent. Consequently, the temporal limit of visual latency in the ReHI at which the biological limb still feels part of the 'self' may decrease accordingly.

Conclusion

We have developed a novel virtual reality paradigm which reduces perceived ownership of one's biological limb in the 'Real Hand Illusion' condition. We recommend the ReHI to be an improvement over existing RHI paradigms when investigating aetiology of disorders such as Xenomelia. This is due to the paradigm more accurately reflecting the phenomenology of the disorder, increasing disownership of one's biological limb, rather than misattribution to a foreign object. Further research is required to reveal a more detailed account of the phenomenology of the paradigm. Additionally, through both anodal and cathodal stimulation, we have provided causal evidence that right parietal regions are involved in the processing of multisensory information which drives feelings of ownership. Future research should investigate whether repeated stimulation of parietal regions may provide therapeutic relief for those with Xenomelia and related disorders.

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APPENDICES

Appendix 1 – Briefing information sheet for study 1

Hand Ownership in VR

uclan University of Central Lancashire | School of Psychology

Thank you for showing interest in this study! This sheet is designed to give you more information about participation in the experiment.

What do you mean by Ownership?

Our brain uses certain processes in order to help distinguish the 'self' from the environment, in other words it's how we know that our body parts belong to us, that we can control them and that they're different from the world around us. Ownership refers to the belief that we are aware of our body parts and we have the knowledge that they belong to 'us'. The current study looks to investigate how these processes work by attempting to disrupt them. For example, if I pointed at your right foot and asked you who this belongs to, you would of course know that it is yours!

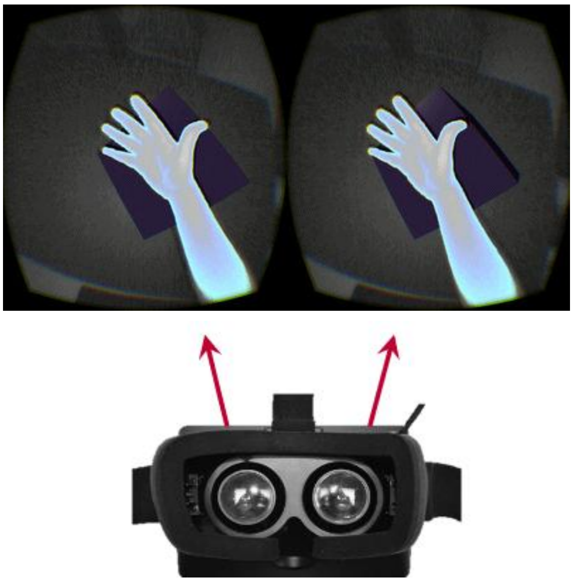
Why VR and is it safe?

We use Virtual Reality as it allows us to strictly control what you see during the study and are not distracted by the environment. It also allows us to create feedback, such as 3D stimuli and CGI hands (computer generated imagery), that would be impossible to provide using conventional screens while hiding your actual hands from view. The VR equipment we use here, i.e. the Oculus Rift SDK 2 and LeapMotion controller, is safe and the risks are comparable to watching TV or playing a computer game.

What will I be asked to do?

You'll be welcomed by the researcher(s) and you will be given a brief on the study explaining the rationale and aims. You'll then be asked to complete (anonymously) a question which measures your perceived interoceptive abilities, this basically looks at how good you think you are at noticing internal changes in your body. For example, this could be how you aware you are of how much you sweat, or how sensitive you are to noticing changes in your heart rate.

As mentioned previously, we will use the LeapMotion controller to track your hand movements and the Oculus Rift SDK 2 to play those movements back to you in a virtual environment. You will see something like this:



During the experiment, you will be asked to keep your hand still whilst you observe a paintbrush stroke the back of your hand/fingers. Once this is complete, you will answer a short questionnaire about you experience of the stroking.

This will be completed twice on your left and your right hand. You will wear the Oculus Rift for a Ymaximum of 5 minutes at a time and the study will last roughly 45 minutes.

You will be awarded a £5 Amazon voucher upon completion of the study.

What happens with my data?

In accordance with the Data Protection Act 1998, only authorised investigators will access experiment data. The data we are collecting from you only relates to your performance on the computerized task and questionnaires. These will be stored on a password-protected computer and/or a locked filing cabinet. Once you have finished the study, your data will only be identifiable by an anonymous code, and will never be referred to individually or by name. The results from this experiment will be written up for publication and may be presented at scientific conferences, but this will involve averages of data obtained from many participants.

You are free to withdraw from the study at ANY time during the experimenting. However, as soon as you leave the room, your anonymised data will be filed with the entire dataset and it will not be possible to withdraw it.

Are there any eligibility criteria?

There are a few of things we need to screen for before we can confirm whether you can participate. We are looking for participants that are over 18 years of age are right handed and speak English proficiently. You must also have good vision (can see in 3D without glasses).

Please take a look at the screening criteria below. You will need to confirm to the experimenter that you do not answer 'Yes' to any of the below questions. If you have any queries, please just ask.

uclan University of Central Lancashire | School of Psychology

Virtual Reality Screening Questionnaire

If you agree to take part in this study, please answer the following questions. The information you provide is for screening purposes only and will be kept completely confidential. Once you have completed this form, please give it to the experimenter. If you have any queries, or do not understand any of the questions, please ask the experimenter.

Have you suffered from epilepsy, febrile convulsions in infancy or recurrent fainting spells? YES/NO

Do you frequently experience periods of nausea or dizziness? YES/NO

Do you currently have any of the following fitted to your body? YES/NO

Heart pacemaker

Cochlear implant

Medication pump

Surgical clips

Neuromodulators/implanted neurostimulators

Any metal in your brain or skull

Are you currently suffering from any illness or general health problems? YES/NO

If YES, please indicate.

Are you left or right handed? LEFT/RIGHT

Participant Consent:

I (please give full name in CAPITALS) ____________________________________

confirm that I have read the letter of invitation and have completed the above questionnaire. The nature, purpose and possible consequence of the procedures involved have been explained. I understand that I may withdraw from the study at any time.

Signature________________________
Date___________________________________

Please note: All data arising from this study will be held and used in accordance with the Data Protection Act (1984). The results of the study will not be made available in a way which could reveal the identity of individuals.

Appendix 2 – Body Perception Questionnaire Short Form (Porges, 1993, 2015).

1

Body Perception Questionnaire Short Form
Stephen W. Porges © 1993, 2015

I. Body Awareness

Please rate your awareness on each of the characteristics described below. Select the answer that most accurately describes you.

During most situations I am aware of:

		Never	Occasionally	Sometimes	Usually	Always
1	Swallowing frequently	o	o	o	o	o
2	An urge to cough to clear my throat	o	o	o	o	o
3	My mouth being dry	o	o	o	o	o
4	How fast I am breathing	o	o	o	o	o
5	Watering or tearing of my eyes	o	o	o	o	o
		Never	Occasionally	Sometimes	Usually	Always
6	Noises associated with my digestion	o	o	o	o	o
7	A swelling of my body or parts of my body	o	o	o	o	o
8	An urge to defecate	o	o	o	o	o
9	Muscle tension in my arms and legs	o	o	o	o	o
10	A bloated feeling because of water retention	o	o	o	o	o
11	Muscle tension in my face	o	o	o	o	o
		Never	Occasionally	Sometimes	Usually	Always

2

		Never	Occasionally	Sometimes	Usually	Always
12	Goose bumps	o	o	o	o	o
13	Stomach and gut pains	o	o	o	o	o
14	Stomach distension or bloatedness	o	o	o	o	o
15	Palms sweating	o	o	o	o	o
16	Sweat on my forehead	o	o	o	o	o
17	Tremor in my lips	o	o	o	o	o
18	Sweat in my armpits	o	o	o	o	o
19	The temperature of my face (especially my ears)	o	o	o	o	o
		Never	Occasionally	Sometimes	Usually	Always
20	Grinding my teeth	o	o	o	o	o
21	General jitteriness	o	o	o	o	o
22	The hair on the back of my neck "standing up"	o	o	o	o	o
23	Difficulty in focusing	o	o	o	o	o
24	An urge to swallow	o	o	o	o	o
25	How hard my heart is beating	o	o	o	o	o
26	Feeling constipated	o	o	o	o	o
		Never	Occasionally	Sometimes	Usually	Always

Appendix 3 – Behavioural Study Debrief Sheet

Virtual Reality Study

Debrief Information

Thank you for taking part in the study. This sheet is designed to tell you more about the aims and design of the study you participated in.

As the experimenter will have already explained, the study aimed to investigate the processes of ownership. In healthy individuals, we have a complete and working ownership of our whole body. This means we are aware of all our limbs and we explicitly and implicitly know that they belong to us. However, some individuals do not recognise one or more of their body parts as being part of their body or that they belong to them. In some rare cases the feeling is so strong that they seek to remove the limb via amputation. These individuals are relatively few, furthermore, each of these individuals are unique in how they are affected. This makes studying their bodily sensations difficult to generalise.

To overcome this, we use simple illusions to recreate symptoms in healthy individuals to better understand where processes may be going wrong. We use Virtual Reality as it allows us to strictly control what you see during the study and are not distracted by the environment. By having such a strict control over what you see and feel it makes it possible for us to disrupt the processes of ownership. In the experiment you answered questionnaires after activities designed to reduce your sense of ownership. Hopefully the results will show that when we use illusions, we can reduce your sense of ownership of your hand.

Definitions:

Ownership – The belief that that body part you are looking at (in this case your hand) is connected to your body and it belongs to you.

Virtual Reality – the computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensor.

Please note that you can still withdraw your data from the study if you wish – just let the experimenter know if this is the case. However, once you leave the room, your anonymised data will be filed with the complete dataset and you will not be able to remove your data.

If you have any comments or further questions about the study, or would like to receive a breakdown of the study findings once data collection is complete, please contact the experimenter, whose details are given at the end of this sheet. If you are unhappy with, or have any concerns about, aspects of the project, you can contact the University Officer for Ethics (officerforethics@uclan.ac.uk), who is entirely independent of the research and will respond to your concerns.

More generally, if you are ever worried about your emotional well-being or general mental health, the university and Samaritans provide sources of support:

UCLan Counselling Service: 01772 892572 corecep@uclan.ac.uk

Samaritans: 08457909090

Thanks again for participating!

Experimenter details:

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Project Supervisor details:

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Appendix 4 – Hand Ownership Questionnaire

Body Perception in VR Questionnaire

DATE:

PARTICIPANT ID:

CONDITION:

AGE:

GENDER:

During the experiment, there were times when…*

*(rate based on the moment where the described perception was strongest)

0 := not at all; 10 := completely

I felt as though the virtual hand was my own.

0 10

It felt as if the stroking I felt on my hand was due to the virtual object I saw stroking the virtual hand.

0 10

I felt as though the stroking I felt on my hand was on the same location as where the virtual hand was stroked.

0 10

It seemed like the virtual hand resembled my own hand in terms of its shape and structure.

0 10

I felt as though I could have moved the virtual hand like my own hand if I wanted.

0 10

It felt as though I was looking at my own hand.

0 10

I felt as though I was looking at another person's hand.

0 10

It felt as though I couldn't tell where my hand was.

0 10

I felt as though my hand had disappeared.

0 10

It felt as though the experience of my hand was less vivid than normal.

0 10

Open comments:

(Please use this space to leave additional feedback/thoughts about the study.)

Appendix 5 – Neurostimulation Briefing Information Sheet

Hand ownership in VR with tDCS

Briefing and Information Sheet

Thank you for showing interest in this study! This sheet is designed to give you more information about participation in the experiment.

What do you mean by Ownership?

Our brain uses certain processes in order to help distinguish the 'self' from the environment, in other words it's how we know that our body parts belong to us, that we can control them and that they're different from the world around us. Ownership refers to the belief that we are aware of our body parts and we have the knowledge that they belong to 'us'. The current study looks to investigate how these processes work by attempting to disrupt them. For example, if I pointed at your right foot and asked you who this belongs to, you would of course know that it is yours!

Why VR and is it safe?

We use Virtual Reality as it allows us to strictly control what you see during the study and are not distracted by the environment. It also allows us to create feedback, such as 3D stimuli and CGI hands (computer generated imagery), that would be impossible to provide using conventional screens while hiding your actual hands from view. The VR equipment we use here, i.e. the Oculus Rift SDK 2 and LeapMotion controller, is safe and the risks are comparable to watching TV or playing a computer game.

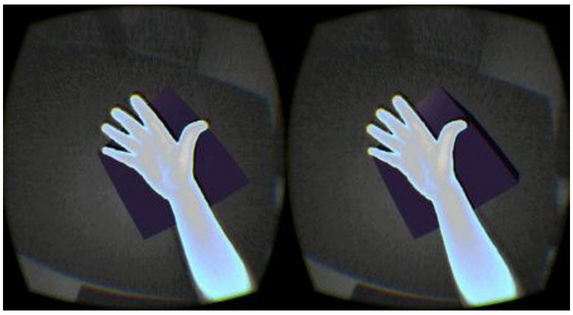
What is tDCS and is it safe?

tDCS (transcranial direct-current stimulation) is used to alter the electrical activity in a specific region of the brain. It works by having two electrodes attached to specific locations on the scalp. A low current is passed from one electrode to the other. Depending which direction the current is travelling, it may increase or decrease the electrical activity in that brain area. By increasing the region's electrical activity, your brain's ability to process information may improve, which may reveal how different brain regions may be responsible for different behaviours. tDCS has been used extensively in the 21st century and is deemed a very safe procedure when the correct procedures are followed. We do have exclusion criteria such as skin conditions (eczema) and if you have a history of epilepsy or brain injuries. Despite the low risk of major adverse events, it's common for participants to feel tingling sensations, headaches and skin redness. If at any point you feel uncomfortable, we can stop the stimulation with immediate effect.

What will I be asked to do?

.

As mentioned previously, we will use the LeapMotion controller to track your hand movements and the Oculus Rift SDK 2 to play those movements back to you in a virtual environment. You will see something like this:



You will then have the two tDCS electrodes placed on your scalp, the stimulation will begin and it will be on for a maximum of 20 minutes. The experiment then beings, you will be asked to keep your hand still whilst you watch the band of your hand being stroked by a paintbrush for 3 minutes. Once this is complete, you will answer a short questionnaire about what you experienced during the stroking phase.

This will be completed twice; you will wear the Oculus Rift for a maximum of 5 minutes at a time and the study will last roughly 60 minutes.

What happens with my data?

In accordance with the Data Protection Act 1998, only authorised investigators will access experiment data. The data we are collecting from you only relates to your performance on the computerized task and questionnaires. These will be stored on a password-protected computer and/or a locked filing cabinet. Once you have finished the study, your data will only be identifiable by an anonymous code, and will never be referred to individually or by name. The results from this experiment will be written up for publication and may be presented at scientific conferences, but this will involve averages of data obtained from many participants.

You are free to withdraw from the study at ANY time during the experimenting. However, as soon as you leave the room, your anonymised data will be filed with the entire dataset and it will not be possible to withdraw it.

Are there any eligibility criteria?

There are a few of things we need to screen for before we can confirm whether you can participate. We are looking for participants that are over 18 years of age are right handed and speak English proficiently. There is also a brief screening questionnaire (below). If you decide you wish to take part in the study, you will be asked to confirm to the experimenter that you do not answer 'Yes' to any of the questions in the questionnaire.

Please contact the experimenter if you have any queries about this.

Please take a look at the screening criteria below. You will need to confirm to the experimenter that you do not answer 'Yes' to any of the below questions. If you have any queries, please just ask.

Virtual Reality/tDCS Screening Questionnaire

University of Central Lancashire | School of Psychology

If you agree to take part in this study, please answer the following questions. The information you provide is for screening purposes only and will be kept completely confidential. Once you have completed this form, please give it to the experimenter. If you have any queries, or do not understand any of the questions, please ask the experimenter.

	Yes	No
Have you ever suffered from epilepsy or ever had a convulsion or seizure?		
1. Do any close relatives (parents, siblings, children) suffer from epilepsy or have had a convulsion or seizure? If yes specify:		
2. Have you ever had a concussion or head trauma resulting in loss of consciousness?		
3. Have you ever had brain surgery?		
4. Do you have a cardiac pacemaker or intracardiac lines?		

5. Do you have metal in the brain, skull or elsewhere in your body (e.g. fragments, splinters, clips etc)? If yes, specify metal and location:		
6. Do you have an implanted neurostimulator (e.g. deep brain stimulation, epidural/subdural, vagus nerve stimulation)?		
7. Do you have a medication infusion device implanted?		
8. Do you have any hearing problems or ringing in your ears?		
9. Do you have cochlear implants?		
10. Are you pregnant or think you may be pregnant?		
11. Have you ever had a fainting spell or syncope? If yes specify on what occasion(s)?		
12. Are you taking any prescribed medication? Please list:		
13. Did you undergo TMS in the past? If yes, were there any problems?		
14. Did you undergo MRI in the past? If yes, were there any problems?		
15. Are you currently suffering from any illness or general health problems?		

16. Do you have eczema?		
17. Are you right or left handed?		

Participant Consent:

I (please give full name in CAPITALS) ____________________________________

confirm that I have read the letter of invitation and have completed the above questionnaire. The nature, purpose and possible consequence of the procedures involved have been explained. I understand that I may withdraw from the study at any time.

Signature________________________
Date___________________________________

Please note: All data arising from this study will be held and used in accordance with the Data Protection Act (1984). The results of the study will not be made available in a way which could reveal the identity of individuals.

Appendix 6 – Neurostimulation study debrief

Neurostimulation Study

Debrief Information

Thank you for taking part in the study. This sheet is designed to tell you more about the aims and design of the study you participated in.

As the experimenter will have already explained, the study aimed to investigate the processes of ownership. In healthy individuals, we have a complete and working ownership of our whole body. This means we are aware of all our limbs and we explicitly and implicitly know that they belong to us. However, some individuals do not recognise one or more of their body parts as being part of their body or that they belong to them. In some rare cases, the feeling is so strong that they seek to remove the limb via amputation. These individuals are relatively few, furthermore, each of these individuals are unique in how they are affected. This makes studying their bodily sensations difficult to generalise.

To overcome this, we use simple illusions to recreate symptoms in healthy individuals to better understand where processes may be going wrong. We use Virtual Reality as it allows us to strictly control what you see during the study and are not distracted by the environment. By having such a strict control over what you see and feel it makes it possible for us to disrupt the processes of ownership. In the experiment you answered questionnaires after activities designed to reduce your sense of ownership. Hopefully the results will show that when we use illusions, we can reduce your sense of ownership of your hand.

There is also some evidence to suggest that when your ownership is affected, it changes your physiological self-regulation. Put more simply, if you experience a loss of ownership in your hand, it may reduce blood flow to that region and reduce the surface temperature of your hand.

By using transcranial direct current stimulation (tDCS), we may be able to change the activity of particular brain regions. In this instance, we were trying to change the activity of your 'right superior parietal lobe'. This is because we believe this area may be involved in putting together the different sensory signals which give you a seamless sensation of having a 'complete' body experience.

<u>Definitions:</u>

Ownership – The belief that that body part you are looking at (in this case your hand) is connected to your body and it belongs to you.

Virtual Reality – the computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensor.

tDCS – equipment which has two electrodes attached to your scalp. One is positive, the other n

egative. A current flows from one to the other, this changes the activity in particular brain regions, which may reveal what the purpose of those brains are.

Please note that you can still withdraw your data from the study if you wish – just let the experimenter know if this is the case. However, once you leave the room, your anonymised data will be filed with the complete dataset and you will not be able to remove your data.

If you have any comments or further questions about the study, or would like to receive a breakdown of the study findings once data collection is complete, please contact the experimenter, whose details are given at the end of this sheet. If you are unhappy with, or have any concerns about, aspects of the project, you can contact the University Officer for Ethics (officerforethics@uclan.ac.uk), who is entirely independent of the research and will respond to your concerns.

More generally, if you are ever worried about your emotional well-being or general mental health, the university and Samaritans provide sources of support:

UCLan Counselling Service: 01772 892572 corecep@uclan.ac.uk

Samaritans: 08457909090

Thanks again for participating!

Experimenter details:

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DATA OUTPUT

Study 1 two-way repeated measure ANOVA output for hand laterality and ReHI effects

Within-Subjects Factors

Measure: Ownership_Score

Hand	ReHI	Dependent Variable
1	1	Left_Control
	2	Left_Illusion
2	1	Right_Control
	2	Right_Illusion

Descriptive Statistics

	Mean	Std. Deviation	N
Left_Control	83.7800	11.77444	20
Left_Illusion	63.1550	21.99453	20
Right_Control	84.1250	14.62215	20
Right_Illusion	69.5600	17.91090	20

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
Hand	Pillai's Trace	.131	2.861[b]	1.000	19.000	.107	.131	2.861	.362
	Wilks' Lambda	.869	2.861[b]	1.000	19.000	.107	.131	2.861	.362
	Hotelling's Trace	.151	2.861[b]	1.000	19.000	.107	.131	2.861	.362
	Roy's Largest Root	.151	2.861[b]	1.000	19.000	.107	.131	2.861	.362
ReHI	Pillai's Trace	.458	16.035[b]	1.000	19.000	.001	.458	16.035	.967
	Wilks' Lambda	.542	16.035[b]	1.000	19.000	.001	.458	16.035	.967
	Hotelling's Trace	.844	16.035[b]	1.000	19.000	.001	.458	16.035	.967
	Roy's Largest Root	.844	16.035[b]	1.000	19.000	.001	.458	16.035	.967
Hand * ReHI	Pillai's Trace	.235	5.837[b]	1.000	19.000	.026	.235	5.837	.630
	Wilks' Lambda	.765	5.837[b]	1.000	19.000	.026	.235	5.837	.630
	Hotelling's Trace	.307	5.837[b]	1.000	19.000	.026	.235	5.837	.630
	Roy's Largest Root	.307	5.837[b]	1.000	19.000	.026	.235	5.837	.630

a. Design: Intercept

Within Subjects Design: Hand + ReHI + Hand * ReHI

b. Exact statistic

c. Computed using alpha = .05

Tests of Within-Subjects Effects

Measure: Ownership_Score

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Hand	Sphericity Assumed	227.813	1	227.813	2.861	.107	.131	2.861	.362
	Greenhouse-Geisser	227.813	1.000	227.813	2.861	.107	.131	2.861	.362
	Huynh-Feldt	227.813	1.000	227.813	2.861	.107	.131	2.861	.362
	Lower-bound	227.813	1.000	227.813	2.861	.107	.131	2.861	.362
Error(Hand)	Sphericity Assumed	1512.728	19	79.617					
	Greenhouse-Geisser	1512.728	19.000	79.617					
	Huynh-Feldt	1512.728	19.000	79.617					
	Lower-bound	1512.728	19.000	79.617					
ReHI	Sphericity Assumed	6191.680	1	6191.680	16.035	.001	.458	16.035	.967
	Greenhouse-Geisser	6191.680	1.000	6191.680	16.035	.001	.458	16.035	.967
	Huynh-Feldt	6191.680	1.000	6191.680	16.035	.001	.458	16.035	.967
	Lower-bound	6191.680	1.000	6191.680	16.035	.001	.458	16.035	.967
Error(ReHI)	Sphericity Assumed	7336.790	19	386.147					
	Greenhouse-Geisser	7336.790	19.000	386.147					
	Huynh-Feldt	7336.790	19.000	386.147					
	Lower-bound	7336.790	19.000	386.147					

Hand * ReHI	Sphericity Assumed	183.618	1	183.618	5.837	.026	.235	5.837	.630
	Greenhouse-Geisser	183.618	1.000	183.618	5.837	.026	.235	5.837	.630
	Huynh-Feldt	183.618	1.000	183.618	5.837	.026	.235	5.837	.630
	Lower-bound	183.618	1.000	183.618	5.837	.026	.235	5.837	.630
Error(Hand* ReHI)	Sphericity Assumed	597.662	19	31.456					
	Greenhouse-Geisser	597.662	19.000	31.456					
	Huynh-Feldt	597.662	19.000	31.456					
	Lower-bound	597.662	19.000	31.456					

a. Computed using alpha = .05

Tests of Within-Subjects Contrasts

Measure: Ownership_Score

Source	Hand	ReHI	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Hand	Linear		227.813	1	227.813	2.861	.107	.131	2.861	.362
Error(Hand)	Linear		1512.728	19	79.617					
ReHI		Linear	6191.680	1	6191.680	16.035	.001	.458	16.035	.967
Error(ReHI)		Linear	7336.790	19	386.147					
Hand * ReHI	Linear	Linear	183.618	1	183.618	5.837	.026	.235	5.837	.630
Error(Hand* ReHI)	Linear	Linear	597.662	19	31.456					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: Ownership_Score

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	451861.922	1	451861.922	684.863	.000	.973	684.863	1.000
Error	12535.908	19	659.785					

a. Computed using alpha = .05

Study 1 post hoc t tests

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Left_Control	83.7800	20	11.77444	2.63285
	Left_Illusion	63.1550	20	21.99453	4.91813
Pair 2	Right_Control	84.1250	20	14.62215	3.26961
	Right_Illusion	69.5600	20	17.91090	4.00500
Pair 3	Right_Control	84.1250	20	14.62215	3.26961
	Left_Control	83.7800	20	11.77444	2.63285
Pair 4	Left_Illusion	63.1550	20	21.99453	4.91813
	Right_Illusion	69.5600	20	17.91090	4.00500

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Left_Control & Left_Illusion	20	.245	.297
Pair 2	Right_Control & Right_Illusion	20	.372	.106
Pair 3	Right_Control & Left_Control	20	.799	.000
Pair 4	Left_Illusion & Right_Illusion	20	.838	.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Left_Control - Left_Illusion	20.62500	22.25789	4.97701	10.20799	31.04201	4.144	19	.001
Pair 2	Right_Control - Right_Illusion	14.56500	18.43344	4.12184	5.93788	23.19212	3.534	19	.002
Pair 3	Right_Control - Left_Control	.34500	8.80158	1.96809	-3.77427	4.46427	.175	19	.863
Pair 4	Left_Illusion - Right_Illusion	-6.40500	12.02823	2.68959	-12.03439	-.77561	-2.381	19	.028

Study 1 ownership questionnaire paired t-tests

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	IL1	6.2025	20	2.94057	.65753
	C1	8.3500	20	1.98262	.44333
Pair 2	IL2	4.8075	20	3.06437	.68521
	C2	6.7375	20	3.33786	.74637
Pair 3	IL3	5.0625	20	3.37256	.75413
	C3	8.6400	20	1.54107	.34459
Pair 4	IL4	7.7600	20	2.23534	.49984
	C4	8.4550	20	1.69534	.37909
Pair 5	IL5	7.1925	20	2.61410	.58453
	C5	8.8925	20	1.41953	.31742
Pair 6	IL6	6.2200	20	2.52703	.56506
	C6	8.3150	20	1.96356	.43906
Pair 7	IL7	6.9800	20	2.05423	.45934
	C7	8.9050	20	1.02814	.22990
Pair 8	IL8	7.6250	20	1.86269	.41651
	C8	9.1075	20	.93108	.20820
Pair 9	IL9	8.6625	20	1.28972	.28839
	C9	9.2325	20	.87934	.19663
Pair 10	IL10	5.8450	20	3.23044	.72235
	C10	7.3175	20	2.16329	.48373

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	IL1 & C1	20	.500	.025
Pair 2	IL2 & C2	20	.480	.032
Pair 3	IL3 & C3	20	.305	.192
Pair 4	IL4 & C4	20	.602	.005
Pair 5	IL5 & C5	20	.233	.324
Pair 6	IL6 & C6	20	.547	.013
Pair 7	IL7 & C7	20	.039	.871
Pair 8	IL8 & C8	20	.320	.169
Pair 9	IL9 & C9	20	.374	.104
Pair 10	IL10 & C10	20	.303	.195

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	IL1 - C1	-2.14750	2.59663	.58062	-3.36276	-.93224	-3.699	19	.002
Pair 2	IL2 - C2	-1.93000	3.27424	.73214	-3.46239	-.39761	-2.636	19	.016
Pair 3	IL3 - C3	-3.57750	3.25311	.72742	-5.10000	-2.05500	-4.918	19	.000
Pair 4	IL4 - C4	-.69500	1.81875	.40669	-1.54620	.15620	-1.709	19	.104
Pair 5	IL5 - C5	-1.70000	2.66883	.59677	-2.94905	-.45095	-2.849	19	.010
Pair 6	IL6 - C6	-2.09500	2.19317	.49041	-3.12143	-1.06857	-4.272	19	.000
Pair 7	IL7 - C7	-1.92500	2.26132	.50565	-2.98333	-.86667	-3.807	19	.001
Pair 8	IL8 - C8	-1.48250	1.79592	.40158	-2.32302	-.64198	-3.692	19	.002
Pair 9	IL9 - C9	-.57000	1.26037	.28183	-1.15987	.01987	-2.023	19	.057
Pair 10	IL10 - C10	-1.47250	3.29918	.73772	-3.01656	.07156	-1.996	19	.060

Study 1 Linear regression output

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	BPQ_Score[b]	.	Enter

a. Dependent Variable: Illusory_Strength

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.070[a]	.005	-.050	2.01957

a. Predictors: (Constant), BPQ_Score

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.362	1	.362	.089	.769[b]
	Residual	73.416	18	4.079		
	Total	73.778	19			

a. Dependent Variable: Illusory_Strength

b. Predictors: (Constant), BPQ_Score

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.885	3.116		.284	.780
	BPQ_Score	.012	.039	.070	.298	.769

a. Dependent Variable: Illusory_Strength

Study 1 ownership questionnaire reliability output

Case Processing Summary

		N	%
Cases	Valid	45	100.0
	Excluded[a]	0	.0
	Total	45	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
.793	10

Case Processing Summary

		N	%
Cases	Valid	46	100.0
	Excluded[a]	0	.0
	Total	46	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics

Cronbach's Alpha	N of Items
.884	10

Study 2 – 3x2 repeated ANOVA Illusion/Stimtype output

Within-Subjects Factors

Measure: Ownership_Scores

Stim	ReHI	Dependent Variable
1	1	Anodal_C
	2	Anodal_I
2	1	Sham_C
	2	Sham_I
3	1	Cathodal_C
	2	Cathodal_I

Descriptive Statistics

	Mean	Std. Deviation	N
Anodal_C	76.3654	22.50984	26
Anodal_I	63.3038	20.68742	26
Sham_C	80.1923	13.44351	26
Sham_I	63.4115	20.02175	26
Cathodal_C	82.6538	13.25058	26
Cathodal_I	68.8885	17.18135	26

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
Stim	Pillai's Trace	.205	3.097[b]	2.000	24.000	.064	.205	6.195	.542
	Wilks' Lambda	.795	3.097[b]	2.000	24.000	.064	.205	6.195	.542
	Hotelling's Trace	.258	3.097[b]	2.000	24.000	.064	.205	6.195	.542
	Roy's Largest Root	.258	3.097[b]	2.000	24.000	.064	.205	6.195	.542
ReHI	Pillai's Trace	.547	30.244[b]	1.000	25.000	.000	.547	30.244	1.000
	Wilks' Lambda	.453	30.244[b]	1.000	25.000	.000	.547	30.244	1.000
	Hotelling's Trace	1.210	30.244[b]	1.000	25.000	.000	.547	30.244	1.000
	Roy's Largest Root	1.210	30.244[b]	1.000	25.000	.000	.547	30.244	1.000
Stim * ReHI	Pillai's Trace	.050	.627[b]	2.000	24.000	.543	.050	1.254	.142
	Wilks' Lambda	.950	.627[b]	2.000	24.000	.543	.050	1.254	.142
	Hotelling's Trace	.052	.627[b]	2.000	24.000	.543	.050	1.254	.142
	Roy's Largest Root	.052	.627[b]	2.000	24.000	.543	.050	1.254	.142

a. Design: Intercept

Within Subjects Design: Stim + ReHI + Stim * ReHI

b. Exact statistic

c. Computed using alpha = .05

Mauchly's Test of Sphericity[a]

Measure: Ownership_Scores

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b] Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Stim	.894	2.681	2	.262	.904	.971	.500
ReHI	1.000	.000	0	.	1.000	1.000	1.000
Stim * ReHI	.864	3.501	2	.174	.880	.942	.500

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept

Within Subjects Design: Stim + ReHI + Stim * ReHI

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: Ownership_Scores

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Stim	Sphericity Assumed	951.038	2	475.519	3.518	.037	.123	7.037	.630
	Greenhouse-Geisser	951.038	1.809	525.773	3.518	.042	.123	6.364	.598
	Huynh-Feldt	951.038	1.942	489.802	3.518	.039	.123	6.832	.620
	Lower-bound	951.038	1.000	951.038	3.518	.072	.123	3.518	.438
Error(Stim)	Sphericity Assumed	6757.435	50	135.149					
	Greenhouse-Geisser	6757.435	45.221	149.431					
	Huynh-Feldt	6757.435	48.542	139.208					
	Lower-bound	6757.435	25.000	270.297					
ReHI	Sphericity Assumed	8240.400	1	8240.400	30.244	.000	.547	30.244	1.000
	Greenhouse-Geisser	8240.400	1.000	8240.400	30.244	.000	.547	30.244	1.000
	Huynh-Feldt	8240.400	1.000	8240.400	30.244	.000	.547	30.244	1.000
	Lower-bound	8240.400	1.000	8240.400	30.244	.000	.547	30.244	1.000
Error(ReHI)	Sphericity Assumed	6811.643	25	272.466					
	Greenhouse-Geisser	6811.643	25.000	272.466					
	Huynh-Feldt	6811.643	25.000	272.466					
	Lower-bound	6811.643	25.000	272.466					

Stim * ReHI	Sphericity Assumed	101.489	2	50.745	.413	.664	.016	.825	.113
	Greenhouse-Geisser	101.489	1.761	57.632	.413	.639	.016	.727	.109
	Huynh-Feldt	101.489	1.884	53.865	.413	.652	.016	.778	.111
	Lower-bound	101.489	1.000	101.489	.413	.526	.016	.413	.095
Error(Stim*ReHI)	Sphericity Assumed	6148.497	50	122.970					
	Greenhouse-Geisser	6148.497	44.025	139.659					
	Huynh-Feldt	6148.497	47.104	130.530					
	Lower-bound	6148.497	25.000	245.940					

a. Computed using alpha = .05

Tests of Within-Subjects Contrasts

Measure: Ownership_Scores

Source	Stim	ReHI	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Stim	Linear		916.305	1	916.305	5.346	.029	.176	5.346	.604
	Quadratic		34.733	1	34.733	.351	.559	.014	.351	.088
Error(Stim)	Linear		4285.343	25	171.414					
	Quadratic		2472.092	25	98.884					
ReHI		Linear	8240.400	1	8240.400	30.244	.000	.547	30.244	1.000
Error(ReHI)		Linear	6811.643	25	272.466					
Stim * ReHI	Linear	Linear	3.220	1	3.220	.019	.890	.001	.019	.052
	Quadratic	Linear	98.269	1	98.269	1.220	.280	.047	1.220	.186
Error(Stim*ReHI)	Linear	Linear	4134.137	25	165.365					
	Quadratic	Linear	2014.360	25	80.574					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: Ownership_Scores

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	819279.148	1	819279.148	683.682	.000	.965	683.682	1.000
Error	29958.349	25	1198.334					

a. Computed using alpha = .05

1. Stim

Measure: Ownership_Scores

Stim	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
1	69.835	3.781	62.048	77.621
2	71.802	2.814	66.007	77.597
3	75.771	2.456	70.714	80.829

2. ReHI

Measure: Ownership_Scores

ReHI	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
1	79.737	2.923	73.718	85.757
2	65.201	3.212	58.587	71.816

3. Stim * ReHI

Measure: Ownership_Scores

Stim	ReHI	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
1	1	76.365	4.415	67.273	85.457
	2	63.304	4.057	54.948	71.660
2	1	80.192	2.636	74.762	85.622
	2	63.412	3.927	55.325	71.499
3	1	82.654	2.599	77.302	88.006
	2	68.888	3.370	61.949	75.828

Study 2 post hoc t tests

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Anodal_C	76.3654	26	22.50984	4.41454
	Anodal_I	63.3038	26	20.68742	4.05714
Pair 2	Anodal_C	76.3654	26	22.50984	4.41454
	Sham_C	80.1923	26	13.44351	2.63649
Pair 3	Anodal_C	76.3654	26	22.50984	4.41454
	Sham_I	63.4115	26	20.02175	3.92659
Pair 4	Anodal_C	76.3654	26	22.50984	4.41454
	Cathodal_C	82.6538	26	13.25058	2.59865
Pair 5	Anodal_C	76.3654	26	22.50984	4.41454
	Cathodal_I	68.8885	26	17.18135	3.36954
Pair 6	Anodal_I	63.3038	26	20.68742	4.05714
	Sham_C	80.1923	26	13.44351	2.63649
Pair 7	Anodal_I	63.3038	26	20.68742	4.05714
	Sham_I	63.4115	26	20.02175	3.92659
Pair 8	Anodal_I	63.3038	26	20.68742	4.05714
	Cathodal_C	82.6538	26	13.25058	2.59865
Pair 9	Anodal_I	63.3038	26	20.68742	4.05714
	Cathodal_I	68.8885	26	17.18135	3.36954
Pair 10	Sham_C	80.1923	26	13.44351	2.63649
	Sham_I	63.4115	26	20.02175	3.92659
Pair 11	Sham_C	80.1923	26	13.44351	2.63649
	Cathodal_C	82.6538	26	13.25058	2.59865
Pair 12	Sham_C	80.1923	26	13.44351	2.63649
	Cathodal_I	68.8885	26	17.18135	3.36954
Pair 13	Sham_I	63.4115	26	20.02175	3.92659
	Cathodal_C	82.6538	26	13.25058	2.59865
Pair 14	Sham_I	63.4115	26	20.02175	3.92659
	Cathodal_I	68.8885	26	17.18135	3.36954
Pair 15	Cathodal_C	82.6538	26	13.25058	2.59865
	Cathodal_I	68.8885	26	17.18135	3.36954

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Anodal_C & Anodal_I	26	.593	.001
Pair 2	Anodal_C & Sham_C	26	.810	.000
Pair 3	Anodal_C & Sham_I	26	.337	.093

Pair 4	Anodal_C & Cathodal_C	26	.662	.000
Pair 5	Anodal_C & Cathodal_I	26	.424	.031
Pair 6	Anodal_I & Sham_C	26	.700	.000
Pair 7	Anodal_I & Sham_I	26	.692	.000
Pair 8	Anodal_I & Cathodal_C	26	.672	.000
Pair 9	Anodal_I & Cathodal_I	26	.474	.014
Pair 10	Sham_C & Sham_I	26	.449	.021
Pair 11	Sham_C & Cathodal_C	26	.704	.000
Pair 12	Sham_C & Cathodal_I	26	.513	.007
Pair 13	Sham_I & Cathodal_C	26	.380	.056
Pair 14	Sham_I & Cathodal_I	26	.551	.004
Pair 15	Cathodal_C & Cathodal_I	26	.343	.086

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Anodal_C - Anodal_I	13.06154	19.56168	3.83636	5.16041	20.96267	3.405	25	.002
Pair 2	Anodal_C - Sham_C	-3.82692	14.03996	2.75346	-9.49779	1.84394	-1.390	25	.177
Pair 3	Anodal_C - Sham_I	12.95385	24.57974	4.82048	3.02588	22.88182	2.687	25	.013
Pair 4	Anodal_C - Cathodal_C	-6.28846	16.95432	3.32502	-13.13646	.55954	-1.891	25	.070
Pair 5	Anodal_C - Cathodal_I	7.47692	21.77478	4.27039	-1.31810	16.27195	1.751	25	.092
Pair 6	Anodal_I - Sham_C	-16.88846	14.80903	2.90429	-22.86996	-10.90696	-5.815	25	.000
Pair 7	Anodal_I - Sham_I	-.10769	15.99252	3.13639	-6.56721	6.35183	-.034	25	.973

Pair 8	Anodal_I - Cathodal_C	-19.35000	15.33152	3.00676	-25.54253	-13.15747	-6.436	25	.000
Pair 9	Anodal_I - Cathodal_I	-5.58462	19.64967	3.85362	-13.52129	2.35206	-1.449	25	.160
Pair 10	Sham_C - Sham_I	16.78077	18.43126	3.61467	9.33622	24.22531	4.642	25	.000
Pair 11	Sham_C - Cathodal_C	-2.46154	10.27253	2.01461	-6.61070	1.68763	-1.222	25	.233
Pair 12	Sham_C - Cathodal_I	11.30385	15.45925	3.03181	5.05972	17.54797	3.728	25	.001
Pair 13	Sham_I - Cathodal_C	-19.24231	19.36593	3.79797	-27.06438	-11.42024	-5.066	25	.000
Pair 14	Sham_I - Cathodal_I	-5.47692	17.79740	3.49036	-12.66545	1.71160	-1.569	25	.129
Pair 15	Cathodal_C - Cathodal_I	13.76538	17.73248	3.47762	6.60308	20.92769	3.958	25	.001

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Anodal	69.8346	26	19.27865	3.78085
	Cathodal	75.7712	26	12.52110	2.45559

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Anodal & Cathodal	26	.740	.000

Paired Samples Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Anodal - Cathodal	-5.93654	13.09251	2.56765	-11.22472	-.64836	-2.312	25	.029