Alterations of body representations associated with passivity symptoms in schizophrenia

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Statement of candidate contribution

This thesis is presented as a collection of papers. I declare that this thesis is my own composition; all sources have been acknowledged and my contribution is clearly identified in the thesis. For any work that has been co-published (or prepared for publication), I have the permission of all co-authors to include this work in my thesis. The contribution of each author is outlined below.

For all papers (chapters two – six), the thesis author (Kyran Graham-Schmidt) contributed to the final design of the studies, recruited the participants, performed the testing of participants, processed, analysed and interpreted the data and wrote the manuscripts.

For chapters two through six, the coordinating supervisor (Mathew Martin-Iverson) assisted in the final design of the studies and provided detailed feedback on the interpretation of data and drafting of manuscripts.

For chapters two through six, the co-supervisor (Flavie Waters) designed the original experiments and provided detailed feedback on the interpretation of data and drafting of manuscripts.

For chapters two, three, four and six, co-author Nicholas Holmes contributed to the final design of the experiments and provided comments on the manuscripts.

For chapter three, co-author Assen Jablensky contributed to the initial design of the study and provided comments on the manuscript.

Matthew Albrecht is equal first author for the published book chapter in Appendix I, and the co-supervisors (Mathew Martin-Iverson and Flavie Waters) both contributed to the publication.

Kyran Graham-Schmidt
06/01/2016

Mathew Martin-Iverson
07.01.2016
Publications arising from this thesis


Abstract

People with schizophrenia and passivity symptoms feel they are not in control of their actions, intentions, thoughts and other somatic experiences, believing them to be controlled by an external agent. A recent hypothesis posits that these symptoms arise from compromised mental and neurological representations of the physical body (‘body representations’). Evidence exists of body representation alterations in schizophrenia, but have been incompletely characterised in this clinical group, and the specificity of such disturbances to passivity symptoms is unclear.

The overall hypothesis of this thesis is that there is a continuum of alterations of body representations (body schema, body image, body structural description, body agency) in all individuals with schizophrenia relative to healthy controls, such that individuals with a past history of passivity symptoms have more pronounced abnormalities of body representations and the most prominent alterations are in people currently experiencing passivity symptoms.

Two samples were used; healthy community controls were used to validate existing tools to assess body representations (projected hand illusion in Chapter 2, and intentional binding task in Chapter 5), and determine the association with selected demographic variables and psychosis-like experiences (PLE). A sample of individuals with schizophrenia with and without passivity symptoms was also tested to assess their performance on tasks assessing body representations (Chapters 3, 4, 6).

In chapter 2, a questionnaire assessing body image and body agency in the projected hand illusion (PHI) was validated in 48 healthy controls. Principle components analysis revealed four components: Embodiment and Disembodiment (body image), Agency (body agency), and Deafference. Increased embodiment of the project hand was positively correlated with PLE scores, and negatively with age.

In chapter 3, body schema (using a hand laterality task; HLT) and body image and body agency (using the PHI) were investigated in people with schizophrenia (Current passivity symptoms = 20; Past history of passivity symptoms, n = 12; and Never experienced these symptoms, n = 21) and healthy controls (n = 48). Abnormal performance on the HLT and PHI, indicated distortions of body schema and body image, respectively, in all individuals with schizophrenia. People with any history (Past & Current) of passivity symptoms showed increased disembodiment and impaired prediction of the body schema and, in the Current group, insensitivity to the 500 ms visuotactile delay in the asynchronous condition.
Chapter 4 assessed body structural description with the in-between task (IBT), and matching body parts by location tasks (MBPBL), and body image with the body distortion questionnaire (including depersonalisation, loss of body boundaries, small and large subscales). Impairment on the IBT, but not the MBPBL, indicated subtle distortions of body structural description in people with schizophrenia. All schizophrenia groups reported body image distortions, with loss of boundary experiences prominent in Current and Past passivity symptoms.

Chapter 5 examined intentional binding, a feature of agency, using an interval estimation procedure (with active and passive movement conditions) in 43 healthy controls. Age was associated with decreased binding, such that older adults experienced perceptual ‘repulsion’, as well as a decrease in the perceived interval. PLE, conversely, were associated with increased binding and an increase in the perceived interval.

Chapter 6 used the same interval estimation procedure as chapter 5, with an additional ‘other’ condition, which comprised the observations of another’s movements, in clinical groups with (n = 15) and without (past or no history) of passivity symptoms (n = 24). Internal timing mechanisms, related to working memory, in schizophrenia were altered such that events were perceived as closer together. Predictive deficits (i.e. no action-modulation of time perception) were found in people with passivity symptoms.

The results show that (i) schizophrenia is associated with broad alterations of body schema, body image, body agency and (partially) body structural description, (ii) individuals with Past and Current passivity symptoms have a specific profile of performance characterised by abnormalities of body image (disembodiment & boundary distortions) and body schema (impaired proprioceptive prediction of actions). In addition, (iii) individuals with Current passivity symptoms had specific predictive deficits and (iv) individuals with schizophrenia showed altered internal timing mechanisms. We propose that the alterations of body schema, body image and body structural description contribute to difficulties in identifying the self and in separating the self from others. In addition, impaired predictive and timing mechanisms lead to a fundamental breakdown in linking events to the self.
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<th>Description</th>
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<tr>
<td>amIPL</td>
<td>Anteromedial inferior parietal lobule</td>
</tr>
<tr>
<td>AMPA</td>
<td>$\alpha$-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid</td>
</tr>
<tr>
<td>ANCOVA</td>
<td>Analysis of covariance</td>
</tr>
<tr>
<td>ANODEV</td>
<td>Analysis of deviance</td>
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<tr>
<td>ANOVA</td>
<td>Analysis of variance</td>
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<tr>
<td>Current</td>
<td>People with an experience of at least two passivity symptoms in the past 4 weeks</td>
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<tr>
<td>dIPFC</td>
<td>Dorsolateral prefrontal cortex</td>
</tr>
<tr>
<td>DS</td>
<td>Digit span</td>
</tr>
<tr>
<td>DSM-IV</td>
<td>Diagnostic and Statistical Manual of Mental Disorders (4th Edition)</td>
</tr>
<tr>
<td>DSM-V</td>
<td>Diagnostic and Statistical Manual of Mental Disorders (5th Edition)</td>
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<tr>
<td>EBA</td>
<td>Extrastriate body area</td>
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<tr>
<td>fMRI</td>
<td>Functional magnetic resonance imaging</td>
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<td>FRS</td>
<td>First-rank (Schneiderian) symptoms</td>
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<td>HLT</td>
<td>Hand laterality task</td>
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<tr>
<td>ICD-10</td>
<td>International Classification of Diseases 10th revision</td>
</tr>
<tr>
<td>mIPFC</td>
<td>Mediolateral prefrontal cortex</td>
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<tr>
<td>MRI</td>
<td>Magnetic resonance imaging</td>
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<tr>
<td>ms</td>
<td>Millisecond</td>
</tr>
<tr>
<td>Never</td>
<td>People with a lifetime history of no passivity symptoms</td>
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<tr>
<td>NMDA</td>
<td>$N$-methyl-$d$-aspartate</td>
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<tr>
<td>NMDAR</td>
<td>$N$-methyl-$d$-aspartate receptor</td>
</tr>
<tr>
<td>Pass. -</td>
<td>People without a history of passivity symptoms in the past 4 weeks</td>
</tr>
<tr>
<td>Pass. +</td>
<td>People with a history of passivity symptoms in the past 4 weeks</td>
</tr>
<tr>
<td>Past</td>
<td>People with a history of at least two passivity symptoms but not in the past 4 weeks</td>
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<tr>
<td>PCA</td>
<td>Principle components analysis</td>
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<td>PET</td>
<td>Positron emission tomography</td>
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<td>PHI</td>
<td>Projected hand illusion</td>
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<tr>
<td>PLE</td>
<td>Psychosis-like experiences</td>
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<tr>
<td>Pre-SMA</td>
<td>Pre-supplementary motor area</td>
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<td>PSI</td>
<td>Passivity Symptoms Interview</td>
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<td>RHI</td>
<td>Rubber hand illusion</td>
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<tr>
<td>Abbreviation</td>
<td>Definition</td>
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</tr>
<tr>
<td>SI</td>
<td>Primary somatosensory cortex</td>
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<tr>
<td>SII</td>
<td>Secondary somatosensory cortex</td>
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<tr>
<td>SAPS</td>
<td>Scale for the Assessment of Positive Symptoms</td>
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<tr>
<td>SANS</td>
<td>Scale for the Assessment of Negative Symptoms</td>
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<tr>
<td>SCAN</td>
<td>Schedules for Clinical Assessment in Neuropsychiatry</td>
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<tr>
<td>SD</td>
<td>Standard deviation</td>
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<td>SEM</td>
<td>Standard error of the mean</td>
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<td>SMA</td>
<td>Supplementary motor area</td>
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<td>SNP</td>
<td>Single nucleotide polymorphism</td>
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<tr>
<td>TMTA</td>
<td>Trail Making Test Form A</td>
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<tr>
<td>TPJ</td>
<td>Temporoparietal junction</td>
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<tr>
<td>WTAR</td>
<td>Wechsler Test of Adult Reading</td>
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Chapter 1 – General Introduction

1.1 Schizophrenia

Schizophrenia is a major psychiatric disorder which is associated with severe disability, sometimes cognitive impairments and a range of clinical symptoms including positive symptoms (such as hallucinations and delusions), negative symptoms (e.g. avolition) and disorganised speech and behaviour. Despite a century of clinical research, schizophrenia remains poorly understood and existing treatment methods are aimed at managing symptoms rather than treating the cause. The disorder is characterised by a loss of contact with reality, core disturbances in the sense of ‘self’, difficulties constructing a stable and enduring view of the self, and disruptions in behaviour that are considered culturally abnormal. Symptoms typically appear during adolescence or young adulthood but follow a different course in individuals; some people experience multiple hospitalisations and a pattern of ongoing deterioration, and others experience one, or few, psychotic episodes, with eventual amelioration of symptoms (Levine, Lurie, Kohn, & Levav, 2011). This heterogeneity in the course of schizophrenia is also shared in all other aspects of the disorder such that the symptom profile, incidence, prognosis, outcomes and response to treatment all vary within and between individuals, time and place (van Os & Kapur, 2009).

1.2 Epidemiology and impact

The number of new cases of schizophrenia in a given population annually varies according to the study but has been estimated to be between 0.16 – 0.46 per 1000 (Jablensky et al., 1992; McGrath et al., 2004), with a lifetime risk of developing the disorder of about 0.72% (McGrath, Saha, Chant, & Welham, 2008; Saha, Chant, Welham, & McGrath, 2005). There are several factors that increase the incidence rate including urban environments (Kirkbride et al., 2006; Mortensen et al., 1999; van Os, 2004), belonging to an ethnic minority (Kirkbride et al., 2008; Veling et al., 2006) and being a male (McGrath et al., 2008).

Active psychosis is ranked as a leading cause of disability (Üstün et al., 1999) and impacts significantly on the quality of life of affected individuals (Browne et al., 1996). The disorder is also associated with poor physical health as a result of obesity, poor diet, smoking and sedentary lifestyles, all of which contribute to a subsequent reduction in life expectancy (Laursen, Munk-Olsen, & Vestergaard, 2012; Saha, Chant, & McGrath, 2007). In addition to the physical effects, schizophrenia is also associated
with poor social outcomes and isolation from the community (Fett et al., 2011) as well as a high comorbidity with affective disorders such as depression and anxiety (Buckley, Miller, Lehrer, & Castle, 2009). As a result, schizophrenia ultimately has a substantial impact on families of those with schizophrenia (Lauber, Keller, Eichenberger, & Rössler, 2005) as well as a high economic burden on healthcare systems and broader society (Carr, Lewin, Neil, Halpin, & Holmes, 2004).

1.3 Risk factors for schizophrenia

1.3.1 Genetics

There is strong evidence that one’s genetic makeup contributes towards a vulnerability of developing schizophrenia. Firstly, the proportion of the variance of schizophrenia as a trait that is explained by genetic variance has been estimated at 80% or above (Cardno et al., 1999; Gottesman, McGuffin, & Farmer, 1987). Secondly, the risk of a person developing schizophrenia steadily increases with increasing degree of relation to a relative with schizophrenia. Given a risk of less than 1% for the general population (Jablensky et al., 1992; McGrath et al., 2004), the risk increases to 6.5% for people with a parent, sibling or child with schizophrenia (Kendler et al., 1993), 5-10% for dizygotic twins (Kringlen, 2000) and 40% for monozygotic twins (Cardno et al., 1999).

The genes implicated in genetic association studies involve genes coding for proteins involved in dopamine signalling, glutamate signalling and neurodevelopment (reviewed by Harrison & Weinberger, 2004) as well as genes involved in immune function (Schizophrenia Working Group of the Psychiatric Genomics Consortium, 2014). It is known that the pattern of heritability for schizophrenia does not follow simple Mendelian inheritance but rather a pattern of complex heritability whereby multiple alleles of different genes each contribute a small, and therefore non-causal, vulnerability to developing the disorder (Roofeh, Tumuluru, Shilpakar, & Nimgaonkar, 2013). Large genome-wide association studies involving single nucleotide polymorphisms (SNPs) have identified many plausible risk variables (e.g. Schizophrenia Working Group of the Psychiatric Genomics Consortium, 2014) but, despite considerable effort to identify key gene(s), the risk conferred by individual risk variables accounts for less than 1 percent of heritability (reviewed by Roofeh et al., 2013; So, Gui, Cherny, & Sham, 2011). Even though there is a known contribution of genetic inheritability to schizophrenia, the highest concordance rates of 50% in
monozygotic twins indicates that there is a significant non-genetic component to the risk of developing schizophrenia.

1.3.2 Environmental factors

There are various environmental factors that can increase the risk of developing schizophrenia. These risk factors can occur perinatally, postnatally, during childhood and during adolescence or early adulthood (Mäki et al., 2005). Perinatal and postnatal factors include (a) advanced paternal age, particularly if the father is above the age of 40, possibly due to a higher accumulation of mutations in the paternal germ line (Sipos et al., 2004; Torrey et al., 2009), (b) complications of pregnancy such as bleeding and pre-eclampsia (Byrne, Agerbo, Bennedsen, Eaton, & Mortensen, 2007), (c) abnormal fetal growth and development (Wahlbeck, Forsén, Osmond, Barker, & Eriksson, 2001), (d) complications of delivery such as uterine atony and asphyxia (Cannon, Jones, & Murray, 2002; Geddes et al., 1999) and (e) prenatal viral infections (Yolken, 2004). Factors that impart a predisposition to schizophrenia during childhood and adolescence – as stated above - are (f) an upbringing in an urban environment compared to rural environments (Kirkbride et al., 2006; Mortensen et al., 1999; van Os, 2004), (g) being a migrant or part of an ethnic minority (Kirkbride et al., 2008; Selten, Cantor-Graae, & Kahn, 2007; Veling et al., 2006), (h) exposure to trauma such as physical, emotional and sexual abuse (M. J. Goldstein, 1987; Morrison, 2003) and (i) poor family relationships including high expressed emotions (Schiffman et al., 2002).

1.4 Neurotransmitter dysregulations in schizophrenia

1.4.1 Dopamine hypothesis of schizophrenia

In regards to the neurobiological mechanisms that underlie schizophrenia, the dopamine hypothesis of schizophrenia has been the predominant model for decades. The hypothesis was first proposed nearly 50 years ago (van Rossum, 1966), and has gone several revisions since, with the latest proposed by Howes and Kapur (2009). Several lines of evidence support the suggestion that dopaminergic dysregulation, namely increased presynaptic dopamine activity in the striatum and the mesocorticolimbic projection areas, leads to the expression of schizophrenia symptoms:

1) All current effective pharmacotherapies are competitive antagonists of dopamine D₂ receptors, except one partial agonist, aripiprazole (Horacek et al., 2006; Seeman, 2006; Seeman & Lee, 1975; Seeman, Lee, Chau-Wong, & Wong, 1976).
2) Both basal and amphetamine-stimulated dopamine release is exaggerated in people with schizophrenia, compared to healthy controls (Abi-Dargham et al., 1998; Abi-Dargham, van de Giessen, Slifstein, Kegeles, & Laruelle, 2009; Breier et al., 1997; Laruelle et al., 1996), an effect possibly due to increased presynaptic dopamine production (Kumakura et al., 2007; Lindström et al., 1999; McGowan, Lawrence, Sales, Quested, & Grasby, 2004; Reith et al., 1994).

3) Amphetamine administered to people with schizophrenia can precipitate psychosis at lower doses than is required to elicit psychotic symptoms in healthy populations (Angrist, Rotrosen, & Gershon, 1980; Laruelle et al., 1996; Lieberman, Kane, & Alvir, 1987).

4) Drugs that increase dopamine transmission (amphetamine, cocaine, L-DOPA, methylphenidate) or that directly activate dopamine receptors, especially dopamine D2-like receptors (pergolide, apomorphine and bromocriptine) can produce a psychotic state in healthy people that is virtually indistinguishable from an acute psychotic episode of schizophrenia (Angrist & Gershon, 1977; Angrist, Thompson, Shopsin, & Gershon, 1975; Boyd, 1995; Damásio, Lobo-Antunes, & Macedo, 1971; Janowsky, El-Yousef, Davis, & Sekerke, 1973; McCormick Jr & McNeel, 1963; Post, 1975). Additionally, when L-DOPA, the precursor that is biosynthesised into dopamine, is given to people with schizophrenia, it worsens their symptoms (Angrist, Sathanathan, & Gershon, 1973).

The case for dopamine dysregulation as a key feature of schizophrenia is strengthened by further findings of increased dopamine transmission, at a level intermediate between people with schizophrenia and the general population, in the extended phenotype of schizophrenia. This includes people in the prodrome (Howes et al., 2009), individuals with schizotypal personality disorder (Abi-Dargham et al., 2004; Mitropoulou et al., 2004), first-degree relatives (Brunelin et al., 2008; Huttunen et al., 2008), those at high-risk of schizophrenia (Myin-Germeys, Marcelis, Krabbendam, Delespaul, & van Os, 2005; Soliman et al., 2007), and in healthy people with psychosis-like experiences (K. C. Chen et al., 2012; Gray, Pickering, & Gray, 1994; Howes et al., 2013; Taurisano et al., 2014; Woodward et al., 2011).

1.4.2 Functional implications of dopamine dysregulation in schizophrenia

The functional significance of increased dopamine in schizophrenia is not well understood. It is well-established that dopamine has a regulatory function in motor-perceptual learning processes, dysfunctions of which may compromise the association
of causality between stimuli, and between actions and stimuli. One such learning process is *incentive salience*, first proposed by Robinson and Berridge (1993). In this, dopamine is responsible for assigning importance to, and motivation to act upon, both external and internal stimuli. The process by which this occurs is sensitised through repeated exposures to the stimuli. In schizophrenia, it has been hypothesised that dopamine hyperactivity causes inappropriate salience to be attributed to otherwise innocuous stimuli and so elicit (inappropriate) attention, emotions or behaviours towards these stimuli (Beninger, 2006). In later years, this framework has been mostly applied to delusions, and to a lesser extent, hallucinations in schizophrenia. As such, delusions are conceptualised as arising from the cognitive appraisal of external stimuli that have been aberrantly labelled as important, and hallucinations arise when internal events (e.g. basal neural firing) have been inappropriately labelled as salient. The content of these mental phenomena is then informed by the cultural and social background and personal narrative of the affected individual (Kapur, 2003; Kapur, Mizrahi, & Li, 2005).

Although the dopamine hypothesis of schizophrenia remains the predominant explanatory hypothesis regarding schizophrenia, there are findings that are not adequately explained by a wholly dopaminergic explanation. For example, one-third of people with schizophrenia do not respond to treatment with D2-receptor antagonists (Kapur, Zipursky, Jones, Remington, & Houle, 2000; Mortimer, Singh, Shepherd, & Puthiryackal, 2010) and D2-receptor antagonists do not improve, or even worsen, cognitive impairments and negative symptoms (see section 1.5 below; Kim et al., 2013; Murphy, Chung, Park, & McGorry, 2006). Therefore, the dopamine hypothesis is usually restricted to the positive symptoms of schizophrenia. These limitations indicate involvement of other neurotransmitter systems in schizophrenia.

### 1.4.3 Glutamate (NMDA receptor hypofunction) hypothesis of schizophrenia

The endogenous agonist of the N-methyl-D-aspartate receptor (NMDAR), glutamate, is the primary excitatory neurotransmitter in the human brain, with 60 – 80% of total brain metabolic activity due to glutamatergic neurons (Rothman, Behar, Hyder, & Shulman, 2003), albeit primarily through the α-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid (AMPA) receptor. The development of the glutamatergic (NMDAR hypofunction) hypothesis in schizophrenia began in the late 1950’s with the development of the dissociative anaesthetics, phencyclidine (PCP) and ketamine (G. M. Chen & Weston, 1960). Soon after their discovery, it was observed that these

Since these initial observations, there are several lines of evidence in support of a localised hypofunction of the NMDAR:

1. Acute administration of non-competitive antagonists of the NMDAR to healthy humans leads to perceptual and psychological effects, including positive and negative symptom-like experiences (see section 1.5 below), that are similar in some ways to symptoms of schizophrenia (Aalto et al., 2005; Adler, Malhotra, Elman, Goldberg, & et al., 1999; Curran & Monaghan, 2001; Curran & Morgan, 2000; Javitt, 2007; Krystal et al., 1994; Lofwall, Griffiths, & Mintzer, 2006; Moore et al., 2013; Moore, Turner, et al., 2011; C. J. A. Morgan & Curran, 2006; C. J. A. Morgan, Mofeez, Brandner, Bromley, & Curran, 2004; Muetzelfeldt et al., 2008; Pomarol-Clotet et al., 2006).

2. Acute administration of ketamine produces cognitive deficits, including working memory impairments (Adler, Goldberg, Malhotra, Pickar, & Breier, 1998; Honey et al., 2004; Honey et al., 2003; Krystal, Abi-Saab, et al., 2005; C. J. A. Morgan, Mofeez, et al., 2004; Roberts, Seymour, Schmidt, Williams, & Castner, 2010; Rowland et al., 2005), semantic fluency deficits (Neill et al., 2011) and impaired sustained attention (Oranje et al., 2000; Passie, Karst, Wiese, Emrich, & Schneider, 2005; Umbricht et al., 2000) that are similar to those that are observed in people with acute psychosis.


4. Administration of ketamine to unmedicated people with schizophrenia exacerbates positive symptoms and can trigger psychosis (Lahti, Holcomb, Medoff, & Tamminga, 1995; Lahti, Koffel, LaPorte, & Tamminga, 1995; Malhotra et al., 1997).

5. Post-mortem examinations have found reduced densities of the NMDAR NR1 subunit in the superior frontal cortex (Sokolov, 1998) and superior temporal cortex (Humphries, Mortimer, Hirsch, & de Belleroche, 1996).
6. Single-photon emission computed tomography (SPECT) has revealed NMDAR hypofunction in the left hippocampus in unmedicated patients (Pilowsky et al., 2005).

7. Two genes, GRIN2A and SRR, that code for the NMDAR subunit NR2A and a protein involved in the transmission pathway of the NMDAR respectively, have been associated with schizophrenia (Schizophrenia Working Group of the Psychiatric Genomics Consortium, 2014). Polymorphisms of the GRIN1 gene/NR1 subunit (Begni et al., 2003; Qin et al., 2005) and GRIN2B gene/NR2B subunit (Allen et al., 2008; Martucci et al., 2006; Qin et al., 2005) have also been associated with schizophrenia.

1.4.4 Cognitive deficits and dopaminergic-glutamatergic interactions

Although there are several hypotheses as to how impaired NMDA signalling contributes to the symptoms of schizophrenia, there is no consensus on a particular hypothesis. However, research has uncovered a complex, interacting network that likely has a significant contribution to the emergence of schizophrenia, comprised of glutamatergic, GABAergic and dopaminergic receptors and projections (see Carli & Invernizzi, 2014; Cohen, Tsien, Goff, & Halassa, 2015; Gruber, Chadha Santuccione, & Aach, 2014 for reviews; Lewis & Gonzalez-Burgos, 2006; Moghaddam & Javitt, 2012).

NMDAR hypofunction may affect cognition in people with schizophrenia as follows: reduced availability/functioning of NMDARs on cortical pyramidal cells that project onto GABAergic interneurons in the midbrain and/or on the GABAergic interneurons themselves causes disinhibition of glutamatergic neurons under the control of the GABAergic interneurons (see Cohen et al., 2015 for a review). This disinhibition leads to release of glutamate from glutamatergic neurons projecting onto the mediolateral prefrontal cortex (mIPFC; Cartmell, Monn, & Schoepp, 1999, 2000; Homayoun, Jackson, & Moghaddam, 2005; Liu & Moghaddam, 1995; Lorrain, Baccei, Bristow, Anderson, & Varney, 2003; Moghaddam, Adams, Verma, & Daly, 1997; Moghaddam & Adams, 1998), leading to increased, but disordered, firing of pyramidal neurons in this brain region (Homayoun & Moghaddam, 2007; Moghaddam & Javitt, 2012). This in turn interrupts cognitive processes dependent on the mIPFC, including impaired attention and perseverative responding (Carli & Invernizzi, 2014).

The disinhibition of GABAergic neurons caused by NMDA hypofunction, as described in the previous paragraph, also leads to hyperactivity of dopaminergic neurons of the midbrain that project to the ventral striatum (Balla, Sershen, Serra,
Koneru, & Javitt, 2003; Breier et al., 1998; Miller & Abercrombie, 1996; Smith et al., 1998; Tsukada et al., 2000; Vollenweider, Vontobel, Oye, Hell, & Leenders, 2000). The increased dopamine transmission in the ventral striatum may then lead to the positive symptoms of schizophrenia (see section 1.4.2 above).

Finally, cortical pyramidal cells also project directly onto dopaminergic neurons of the ventral midbrain, which feedback to the dorsolateral prefrontal cortex (dlPFC; Sesack & Carr, 2002). NMDAR hypofunction of these pyramidal neurons leads to hypoactivation of the dopaminergic neurons, reduced dopamine transmission, and hypoactivation of the dlPFC in people with schizophrenia (Berman, Zec, & Weinberger, 1986; Garrity et al., 2007; Menon, Anagnoson, Mathalon, Glover, & Pfefferbaum, 2001; Pomarol-Clotet et al., 2008; Weinberger, Berman, & Illowsky, 1988; Weinberger, Berman, & Zec, 1986). This hypodopaminergic state in the dlPFC has been proposed to be responsible for cognitive deficits such as impaired working memory (Davis, Kahn, Ko, & Davidson, 1991; Lewis & Gonzalez-Burgos, 2006; Sesack & Carr, 2002; Weinberger, 1987).

It is important to note that there are extensive reciprocal interactions between the dopaminergic and glutamatergic systems. As such, it is not certain if the glutamate or dopamine disruption is primary and drives changes in the other system (Howes, McCutcheon, & Stone, 2015). Accordingly, different authors have emphasised the importance of different neurotransmitter system abnormalities to schizophrenia (Coyle, 2006; Harrison & Weinberger, 2004; Moghaddam & Javitt, 2012; Olney & Farber, 1995; Stone, Morrison, & Pilowsky, 2007).

1.5 Symptoms of schizophrenia: the positive, negative and cognitive disorganisation dimensions

As outlined above, there is considerable variation in the presentation of the symptoms of schizophrenia, both within the individual over the course of their illness, and between individuals. In the past 30 years or so, a prevailing goal has been to examine the symptoms of schizophrenia with a view to impose some prevailing structure. Accordingly, symptoms were subdivided into two (Crow, 1980, 1981, 1985) and three (Liddle, 1987) major subgroups of symptoms, which include positive, negative and cognitive disorganisation symptoms.
1.5.1  Positive symptoms

Positive symptoms are perhaps the most notable symptoms of schizophrenia, and a severe, acute presentation of these symptoms is typically regarded as a manifestation of a psychotic episode. Positive symptoms are most effectively reduced with treatment by antipsychotic medication. A number of symptoms are included in the positive symptom classification. These include hallucinations, which are percepts that occur in the absence of external stimuli, while awake, and which can occur in any sensory modality (auditory, tactile, visual, somatic, olfactory and gustatory). Of these, auditory hallucinations are the most common and occur in approximately 70% of individuals with schizophrenia (Mueser, Bellack, & Brady, 1990). Another group of symptom are delusions, which are fixed and false beliefs that are not changed by compelling evidence or counterargument to the contrary. Delusions can take on many different forms such as delusions of jealousy, delusions of guilt/sin, delusions of mind reading, delusions of reference, grandiose delusions, religious delusions and paranoid/persecutory delusions. Delusions of persecution are the most common form and occur in up to 80% of people with schizophrenia (Sartorius et al., 1986; Stompe et al., 1999; Suhail, 2003). The first-rank (or Schneiderian symptoms, or passivity symptoms) of schizophrenia (third-person auditory hallucinations, voices commenting or discussing, thought echo, thought insertion, thought broadcast, thought commentary, thought block, thought withdrawal, replacement of will by external force) are often also included as positive symptoms of schizophrenia (e.g. Andreasen, 1984b). The importance of these symptoms will be discussed later.

1.5.2  Negative symptoms

Negative symptoms are symptoms that represent loss or impairment of normal functions and behaviour. Negative symptoms consist of alogia (including poverty of speech, poverty of content, blocking and increased latency of response), asociality/anhedonia (lack of recreational activities, lack of pleasure, decreased sexual interest and pleasure, poor and few relationships with friends and peers), avolition/apathy (reduced grooming/hygiene, impersistence at task completion, physical anergia) and affective flattening (unchanging facial expressions, decreased movement, paucity of expressive gestures, poor eye contact, affective non-responsivity, no vocal emphasis) (Andreasen, 1984a). These symptoms are important clinically as the severity of these symptoms is a strong predictor of chronic disability (Perkins, Gu, Boteva, & Lieberman, 2005). However, unlike positive symptoms, antipsychotic medications have
a very modest effect of ameliorating negative symptoms (Angrist et al., 1980; Erhart, Marder, & Carpenter, 2006; Leucht, Pitschel-Walz, Abraham, & Kissling, 1999; Möller, 2003; Tollefson & Sanger, 1997). Cognitive deficits such as impairment of working and long-term memory, speed of processing and attention have also been reported to correlate with negative symptoms (Nieuwenstein, Aleman, & de Haan, 2001; Rossell, Coakes, Shapleske, Woodruff, & David, 2003).

1.5.3 Cognitive and behavioural disorganisation

The third category of symptoms is that of cognitive and behavioural disorganisation. This category consists of positive formal thought disorder (derailment, tangentiality, incoherence, illogicality, circumstantiality, pressure of speech, distractible speech, clanging), bizarre behaviour (in clothing and appearance, social and sexual behaviour, aggressive and agitated behaviour and repetitive or stereotyped behaviour) and inappropriate or incongruous affect (Andreasen & Grove, 1986). The presence of severe formal thought disorder at illness onset is also associated with a worse clinical outcome (Barrera, McKenna, & Berrios, 2009; Harrow & Marengo, 1986).

1.6 First-rank (Schneiderian) symptoms

First-rank (Schneiderian) symptoms traditionally refer to a set of symptoms with fundamental disturbances in the sense of self. For the purposes of this thesis, a broad definition of the sense of self will be employed: here the sense of self refers to the recognition of one as an entity that is unique and independent of others, capable of performing actions and producing change in the external environment and of perceiving both internal and external events.

Prior to the two and three-dimension descriptions of schizophrenia that were produced in the late 1980’s, the clinical psychopathological texts of early European psychiatrists such as Kurt Schneider, Emil Kraepelin and Karl Jaspers in the earlier parts of the 20th century prevailed in clinical psychiatry practice and research. These approaches focused on the elucidation of the patient’s own inner perspectives and experiences (phenomenology), rather than the observation of behaviour.

It has been recognised since the early descriptions of schizophrenia (‘dementia praecox’) that there are fundamental changes in the self. Kraepelin (1913) described a loss of inner unity of consciousness (“The chaos in the mind is like an orchestra without a conductor”) and a devastation of will, and thought these to be the core deficits of schizophrenia. In schizophrenia, Bleuler (1911) also saw “the most manifold
disruptions” in the patient’s ego, including a tearing or splitting apart of mental functions and a reduction in the capacity to direct actions and thoughts. However, the focus of this thesis is on the contribution of Kurt Schneider to a set of symptoms known as first-rank symptoms.

1.6.1 Historical description of first-rank symptoms (Kurt Schneider, 1946)

The first comprehensive description of first-rank symptoms (FRS) was conducted by the German psychiatrist, Kurt Schneider. In his research on schizophrenia, Schneider’s aim was to identify and describe symptoms that would differentiate schizophrenia from other forms of psychosis, particularly affective psychosis. As such, the first-rank symptoms are so named because Schneider believed them to hold significant (‘first rank’) diagnostic importance when determining a diagnosis of schizophrenia (Schneider, 1946). His description of first-rank symptoms was heavily influenced by the continental European philosophical-phenomenological tradition stemming from the work of Edmund Husserl and Karl Jaspers.

Schneider thought these disturbances in the sense of self to be the defining characteristic of schizophrenia, specifically disturbances in the ownership of internal processes. In his words, first-rank symptoms constitute “a lowering of the ‘barrier’ between the self and the surrounding world, the loss of the very contours of the self” (p. 134; Schneider, 1946). Instead of the usual experience of thoughts, emotions, and sensations, he explained that people with schizophrenia had intentions and impulses which are felt as being under the influence or direct control of an external agent. Importantly, these two components (loss of self-boundaries and control by an external agent) are both experienced by the person with schizophrenia. The symptoms, their definitions and examples of each can be seen in Table 1.1.

Up until the 4th Edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) and in the International Classification of Disease 10th revision (ICD-10), first-rank symptoms had critical weighting in giving a diagnosis of schizophrenia. For several decades after the initial description of first-rank symptoms by Schneider, there were some minor revisions and suggestions as to how these symptoms should be defined (Mellor, 1970a; M. A. Taylor & Heiser, 1971; Wing, Cooper, & Sartorius, 1974), however, the majority of the symptoms were maintained. Eventually the phenomenological approach was superseded and the influence of the concept of the self diminished, as the need for objectivity and verification in diagnosis lead to the
emergence and eventual dominance of the DSM and ICD in psychiatry and schizophrenia research (Parnas, Sass, & Zahavi, 2012).

### 1.6.2 Current research classification and usage of passivity symptoms

Two issues have led to the reclassification of the first-rank symptoms. The first was the accumulation of evidence that first-rank symptoms occur in psychoses other than schizophrenia. This has led to the development of a more comprehensive classification system that includes a range of symptoms that were previously considered to be passivity symptoms of schizophrenia. Table 1.1 illustrates the first-rank and passivity symptoms of schizophrenia, as classified by clinical interview.

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Symptom description</th>
<th>Example (in the person’s own words)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voices commenting or discussing a, b</td>
<td>Hallucinated voices that give a running commentary on the patient or talk about the patient in the third person.</td>
<td>One time I was cleaning my room and I had a pile of washing and I was picking up each thing... Every piece of clothing that I picked up, these voices commented &quot;she got that from there and it cost her that much&quot;. [The voices say] &quot;She's not going to eat now, she's going wait until half past 7 and then go to the shops to get something, then she'll come home and eat and have her medication&quot;.</td>
</tr>
<tr>
<td>Loud (audible) thoughts a, b</td>
<td>Thoughts seem so loud in person’s head that someone nearby could hear them.</td>
<td>It’s like turning the radio up to 10 and talking like we are and trying to talk over the top of it...I can hear them [my thoughts].</td>
</tr>
<tr>
<td>Thought insertion a, b</td>
<td>Thoughts are experienced as not being the patient’s own. Often experienced as being inserted by an external agent.</td>
<td>Satan's always trying to put thoughts in my mind but I'm too strong for him... Satan's putting thoughts into my mind to kill and harm people.</td>
</tr>
<tr>
<td>Thought broadcast a, b</td>
<td>Thoughts are experienced as being accessible to others, sometimes as if they are</td>
<td>The voices I hear talking are making [my thoughts] public but I'm not making them public. The</td>
</tr>
<tr>
<td>Thought commentary</td>
<td>A second stream of thoughts (not voices) present in the mind that comment on the persons thoughts and actions.</td>
<td>Yes, the thoughts are my brothers’ thoughts. It could be about something someone has said to me that repeats in my mind, like &quot;it's wrong&quot; or &quot;I don’t agree with that&quot;.</td>
</tr>
<tr>
<td>--------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Thought withdrawal</td>
<td>Thoughts are being actively extracted from the person’s mind, typically by an external agent.</td>
<td>I try and memorise things but Satan locks it up and pulls the thoughts out of my head, rips them out.</td>
</tr>
<tr>
<td>Thought block</td>
<td>Train of thought is stopped abruptly and without control, sometimes by an external agent.</td>
<td>I just have nothing in my mind, it goes empty and locks up... It just seems to happen by itself.</td>
</tr>
<tr>
<td>Thought echo</td>
<td>Patient hears echo of their thoughts in the form of a voice after they have made the thought.</td>
<td>[I am] just thinking about what to say or something and I hear a voice [in my head] like an echo.</td>
</tr>
</tbody>
</table>
| Replacement of will by external force | Actions, intentions, sensations and/or feelings no longer are made by the person, often experienced as being under the control of an external agent. | 1. I was being controlled all the time, by aliens, voices, people up there. I thought they could tap into my mind with telepathy and use me. They were controlling my mind.  
2. I used to get the feeling that I was a passenger inside my own head and that I was looking out through a window behind my eyes and that I had no real control over my body. |
| Delusional perception | Change in familiar perception that takes on significant meaning, often with self-reference.       | I saw the sky change colour and I knew that the world was going to end and I had to save it. |
Based on Scales for Clinical Assessment in Neuropsychiatry (SCAN) definitions

Schneiderian first-rank symptoms

Passivity symptoms

than schizophrenia, including affective psychosis, personality disorders and temporal lobe epilepsy, albeit at a lower incidence than in schizophrenia (Carpenter, Strauss, & Bartko, 1973; Carpenter, Strauss, & Muleh, 1973; Marneros, 1985, 1988). This has resulted in the downgrading of the diagnostic weight of first-rank symptoms in the most recent version of the DSM (DSM-V).

The second major issue is the apparent heterogeneity in the symptoms included under the first-rank grouping. Particularly, the symptoms thought echo and delusional perception, idea and mood do not feature the important phenomenological experience of loss of ownership of thoughts or actions, breakdown in the boundaries of the self or replacement of agency. Such heterogeneity makes it difficult to hypothesise an appropriate neurocognitive or neuropsychological framework encompassing all the first-ranks symptoms without elaborate and tentative speculation (Schneider, 1946; Waters, 2015). This heterogeneity also suggests that the first-rank symptom grouping includes several phenomena with possibly diverse mechanisms (Waters, 2015).

For the purpose of research, a ‘passivity symptom’ cluster has thus emerged in the past 20 years or so as a means to improve homogeneity within this symptom dimension. ‘Passivity symptoms’ now refers to a subgroup of first-rank symptoms which share the phenomenological experiences of thoughts and actions no longer being under the control of the person, a lack of the normal sense of ownership of thoughts and actions, a disturbed boundary between the self and others and the feeling that the will or intention of the person is replaced by that of an external agent (see Table 1.1 for the list of passivity symptoms). This re-classification is supported by many researchers who support categorical distinctions within the first-rank symptoms (Carpenter, Strauss, & Muleh, 1973; Gallagher, 2004; McGorry, Bell, Dudgeon, & Jackson, 1998; Nordgaard, Arnfred, Handest, & Parnas, 2008; Schneider, 1946), and evidence from epidemiological, neurocognitive, imaging and neurobiological studies (see section 1.6.4).

An important distinction must also be made between passivity symptoms and delusions. Passivity symptoms, particularly replacement of will or intention, are still often erroneously classed as a subtype of delusion; for example the Scale for the Assessment of Passivity Symptoms (Andreasen, 1984a) lists replacement of will or
intention by external force as ‘delusions of control’. Phenomenologically, passivity symptoms are perceptual experiences – compared to delusions which are changes in beliefs and cognition. The primary experience of passivity symptoms is a change in the perception of self-generated events such that they no longer feel as if they originate from the self (compare this to the definitions of hallucinations and delusions given in section 1.5.1; Nordgaard et al., 2008; Sass & Parnas, 2003). Another important feature of passivity symptoms is that they are passively experienced, in the sense that they are not under conscious control of the person experiencing them and so involve an absence of a normally present experience (Sass & Parnas, 2003). This primary experience is then often followed by a delusional elaboration to make sense of and/or explain the perceptual experience (Wing et al., 1990). This separation of the primary experience and delusional elaboration is supported by examples of people with passivity symptoms who also often describe the primary experience without a delusional elaboration (e.g. see example 2 of replacement of will by external force in Table 1.1). This separation of primary experience and delusional elaboration is strongly supported by numerous phenomenological descriptions of passivity symptoms. These studies have tracked the development of passivity symptoms from basic disturbances in the experience of self-initiated events, to alienation from these self-processes, through to the full experience of an external locus of control over internal events (Hirjak, Breyer, Thomann, & Fuchs, 2013; Klosterkötter, 1988; Joachim Klosterkötter, 1992; Joachimim Klosterkötter, 1992; Köhler, 1979). The inclusion of voices commenting or discussing in this definition has been inconsistently applied in research, perhaps due to concerns regarding whether ego-boundary disturbances could apply to linguistic processes in hallucinated voices, which are tied to social implications and therefore non-egoistic (Waters, 2015).

1.6.3 Epidemiology of FRS/passivity symptoms

Most epidemiological studies were conducted in the 1960s and 1970s and have focused on prevalence rates of FRS so these are reported here. Studies have found that 40 to 80% of people diagnosed with schizophrenia experience at least one such symptom during the course of their illness (Carpenter, Strauss, & Muleh, 1973; Mellor, 1970a; O'Grady, 1990; Peralta & Cuesta, 1999; Thorup, Petersen, Jeppesen, & Nordentoft, 2007). The two most rigorous studies, reflected in sample sizes and interview methodology, found rates of 57% (Carpenter & Strauss, 1974) and 79% (Mellor, 1970a) respectively. The lifetime median number of FRS is two (O'Grady, 1990), with loud thoughts, thought insertion and replaced control of will/intentions
being the most common experienced symptoms (Carpenter, Strauss, & Muleh, 1973; Chopra & Gunter, 1987; Mellor, 1970b; O'Grady, 1990). Importantly, the validity of these symptoms is supported by epidemiological evidence that demonstrates that these symptoms occur with similar frequencies in different areas of the world and in different cultures (Carpenter & Strauss, 1974; Jablensky et al., 1992). These same studies also provided phenomenological evidence for the validity of such symptoms, with descriptions of the symptoms again showing cross-cultural similarities.

1.6.4 Evidence supporting passivity symptoms as a distinct dimension

In addition to the distinct phenomenology of passivity symptoms outlined in section 1.6.2, there are several other lines of evidence that support the distinction of passivity symptoms from other symptom groups of schizophrenia. Epidemiological studies have demonstrated that multiple passivity symptoms tend to co-occur in the same person, with 50 to 60% of people with schizophrenia experiencing two or more symptoms (Carpenter, Strauss, & Muleh, 1973; Jablensky et al., 1992; Peralta & Cuesta, 1999). This is further supported by studies employing factor analysis of global or positive symptomatology in first-episode psychosis (McGorry et al., 1998; Shtasel et al., 1992) and in people with a confirmed diagnosis of schizophrenia (Cardno et al., 1996; Kimhy, Goetz, Yale, Corcoran, & Malaspina, 2005; Van Os et al., 1996) that have uncovered factors consisting primarily of passivity symptoms. In addition, factor and principal component analyses of the first-rank symptoms themselves have found a distinct factor composed of passivity symptoms (Heering, van Haren, & Derks, 2013; Loftus, Crow, & Delisi, 2000; Peralta & Cuesta, 1999). Longitudinal studies have also demonstrated that the presence of passivity symptoms is stable, i.e. present more than once, through the course of the illness, at both three year (Heering et al., 2013) and 20 year follow up (Rosen, Grossman, Harrow, Bonner-Jackson, & Faull, 2011).

Studies into the genetics of first-rank symptoms also show a different pattern of heritability of vulnerability to first-rank symptoms that is distinct from other positive symptom clusters (Cardno, Sham, Farmer, Murray, & McGuffin, 2002; Loftus et al., 2000). A more recent study using a novel genome-wide associability technique demonstrated that a distinct phenotype of schizophrenia, characterised by passivity symptoms, has a pattern of inheritance that is determined by a defined allele set (Arnedo et al., 2014).

Finally, neuroimaging studies have delineated a distributed but distinct network of brain regions associated with passivity symptoms. The right angular gyrus of the
parietal cortex is activated when a movement is perceived to be induced by an external agent (Farrer et al., 2004; Farrer et al., 2003). Functional MRI (fMRI) and positron emission tomography (PET) have consistently implicated hyperactivity of the right angular gyrus in people experiencing passivity symptoms, both in resting state/task-free environments (Franck, O'Leary, Flaum, Hichwa, & Andreasen, 2002) and when participants were instructed to perform spontaneous, freely chosen movements (Ganesan, Hunter, & Spence, 2005; S. A. Spence et al., 1997). A study in which participants were asked to produce spontaneous movements that controlled an image of a virtual hand on a screen, of which the degree of movement control could be manipulated by the experimenter, also found hyperactivation of the right angular gyrus in people with schizophrenia (Farrer et al., 2004). Further, the degree of activation was positively correlated with the presence of passivity symptoms. This same study found that people with passivity symptoms did not show activation of the insular cortex in conditions when they were in most control of the outcomes of their actions (Farrer et al., 2004); the insular cortex is typically activated in healthy controls when they feel they are the initiator of their actions (Farrer & Frith, 2002). The cingulate gyrus, a region proposed to be a linking area between long-term planning and intentions and implementation of motor sequences (Devinsky, Morrell, & Vogt, 1995; Paus, 2001), has also been found to be hyperactivated during spontaneous movements performed by people with passivity symptoms (S. A. Spence et al., 1997). Activity related to representations of tactile stimulation in the SII somatosensory cortex is typically suppressed after self-initiated movements in healthy controls (Shergill et al., 2013). Conversely, individuals with passivity symptoms did not display this attenuation of SII activity, a finding the authors proposed is due to a failure of sensory predictive processes in this sample (see section 1.7.1 for a description of the proposed mechanism; Shergill et al., 2014).

Finally, structural imaging studies also show a reduction in volume of the right posterior cingulate, the left anterior parahippocampal gyrus (M. Suzuki et al., 2005) and reduced thickness of the right inferior parietal lobule, particularly the angular gyrus (Ganesan, Jayakumar, Keshavan, & Gangadhar, 2011) in people with passivity symptoms.

The implication of the right parietal cortex in passivity symptoms, from both functional and structural imaging, is particularly important as it is known that this region is specifically concerned with dynamic updating of egocentric spatial coordinates with changes in the environment due to voluntary movements (Andersen, Snyder,
Bradley, & Xing, 1997; Lou et al., 2004), is activated preferentially by movements in extrapersonal space (Colby & Goldberg, 1999; Vogeley & Fink, 2003) and is also a particularly important circuit involved in self and non-self differentiations (P. L. Jackson & Decety, 2004; Lou et al., 2004; Seger, Stone, & Keenan, 2004).

1.7 Theoretical models of passivity symptoms

In comparison to other symptoms of schizophrenia, passivity symptoms have received relatively little attention in the scientific literature and as a result, they remain poorly understood. Two main neurocognitive frameworks have dominated the literature since the 1980s: the forward model and cognitive self-monitoring models. Other models exist but tend to be variations or syntheses of these two frameworks (see Moore & Fletcher, 2012; Synofzik, Vosgerau, & Newen, 2008, where agency is inferred from an integration of predictive cues and retrospective inferences). It is important to note that the fundamental tenet of both these models is that at their core, passivity symptoms are disorders of agency, and therefore we must seek to understand passivity symptoms through the study of motor control, since agency is fundamentally tied to actions. The two models will be discussed in turn.

1.7.1 The central monitoring comparator/forward (efference copy) model

Initially known as the central monitoring comparator model, this model was first proposed in the late 1980s to explain visual processing, and was concerned with how the brain adjusts visual processing to compensate for movements of the head. The central monitoring model was proposed as an explanatory model for the precise execution of motor commands (Feinberg, 1978). It was then later proposed as the process by which agency is attributed to self-made movements and as the neuropsychological process that is deficient in passivity symptoms (Frith, 1987; Frith & Done, 1988). A later, updated version of the comparator model, termed the forward model, was developed by Miall and Wolpert (1996). The forward model was conceived as follows: voluntary actions are initiated by a motor command, a copy of which is sent to the relevant sensory processing areas of the brain. This copy is subsequently termed the corollary discharge or efference copy (Angel, 1976; Feinberg, 1978) and contains a representation of the expected sensory consequences of the motor command. The information contained within relates to the timing and spatial coordinates of the body parts involved in the movement (kinematics) and the sensations that movement will cause. The predicted sensory feedback is then compared with the actual sensory
feedback; if the prediction and outcomes match, then the action must been self-produced and so agency is attributed to the action. Further, the predictions are used to attenuate the sensory outcomes of that action. For example, we cannot tickle ourselves, but others can, because the efference copy attenuates the tactile sensations during a self-produced tickle but not for an externally-produced tickle (Blakemore, Wolpert, & Frith, 2000). This function allows self-made sensations to be distinguished from externally-generated ones and has the effect of accentuating particularly important, i.e. non-self generated, sensory information (Blakemore, Wolpert, et al., 2000). The original model of passivity symptoms of schizophrenia posited that these symptoms are a breakdown in this comparator model such that self-made internal events are not properly labelled as such (Frith, 1987; Frith & Done, 1988).

1.7.2 Evidence of forward model deficits in schizophrenia

The first evidence for a dysfunctional forward model came from a study that found that people with schizophrenia (n = 14) were significantly less likely to make error corrections on a visuomotor task assessing the ability to compensate for motor errors in the absence of visual information (Malenka, Angel, Hampton, & Berger, 1982), which was interpreted as a deficit in the forward model. The specificity of forward model deficits is not clear; one study with the same task found that these deficits were unique to people with passivity symptoms (Frith & Done, 1989) while other studies have found deficits in the forward model in people with schizophrenia undifferentiated by symptom profile (Stirling, Hellewell, & Quraishi, 1998; Turken, Vuilleumier, Mathalon, Swick, & Ford, 2003).

As the literature has expanded, findings of impaired sensory and kinematic prediction have been relatively consistent. Reductions in the precision of the predictive component of the forward model have been demonstrated in visual (Lindner, Thier, Kircher, Haarmeier, & Leube, 2005; Synofzik, Thier, Leube, Schlotterbeck, & Lindner, 2010), tactile (Blakemore, Smith, Steel, Johnstone, & Frith, 2000), proprioceptive (Franck et al., 2001) and kinematic (Shergill, Samson, Bays, Frith, & Wolpert, 2005) modalities. Further, the level of imprecision of sensory prediction has been demonstrated to be positively correlated with the severity of passivity symptoms (Lindner et al., 2005; Synofzik et al., 2010). The functional outcome of this deficit is that people with passivity symptoms are not able to accurately predict the outcomes of actions. As a result, people with passivity symptoms display a particularly pronounced insensitivity to distorted sensory feedback and so are more likely to report that a hand
displayed on a video screen is their own, even when the hand is someone else’s and/or performing different movements to their own hand (Daprati et al., 1997; Schnell et al., 2008).

Overall, much evidence has been found in support of a deficiency in the forward model in people with passivity symptoms. However, despite this research, the forward model has attracted criticism.

### 1.7.3 Criticisms of the forward model

Several authors have questioned the adequacy of disruptions of the forward model in explaining passivity symptoms (Cermolacce, Naudin, & Parnas, 2007; Gallagher, 2004; Vosgerau & Newen, 2007; Waters & Badcock, 2010). One difficulty is that the forward model focuses on actions, when passivity symptoms include multiple experiences such as actions, perception, thoughts and emotions. Originally, it was claimed the forward model was able to explain motor and non-motor (thought) passivity symptoms. This was based on the assumption that thoughts, perceptions and emotions are all overt (thoughts) or covert (actions) intentional behaviours, are subject to the same sensorimotor processes and hence can be explained entirely by a breakdown of motor control, namely of the forward model (Frith, 1987, 1992; Frith & Done, 1988). However, there is little behavioural or neuropsychological evidence that supports this claim (Gallagher, 2004; Synofzik et al., 2008; Vosgerau & Newen, 2007; Waters & Badcock, 2010).

Further theoretical critiques relate to the correct interpretation of the outcome of a breakdown of the forward model; such deficits may explain why a person no longer feels in control of their actions but it does not explain why the person then attributes agency to an external agent (Gallagher, 2004; G. Graham & Stephens, 2000). There is evidence supporting this criticism. Firstly, people with depersonalisation disorder often describe being as if they are under the control of another, alien agent but retain intact reality testing and are able to correctly determine the unusual experience is just a feeling. This indicates that there are clinical conditions in which a lack of volition over actions can be felt without subsequent feelings of being under control of another (Davies, Coltheart, Langdon, & Breen, 2001). A further study in healthy human controls has also demonstrated that the experience of not being in control is not necessary in developing the feeling of being under the control of an external agent (Blakemore, Oakley, & Frith, 2003).
Another criticism is that problems with the forward model should precipitate gross motor problems in people with passivity symptoms. This is contradicted by findings that adjustments of grip-force in resisting self- or other-imposed collisions is not impaired in people with passivity symptoms, compared to healthy controls and people with schizophrenia without passivity symptoms. These findings indicate that people with passivity symptoms are accurately able to adapt their motor responses to changing conditions and so the low-level automatic motor control that is key to the forward model is not impaired in these people (Delevoye-Turrell, Giersch, & Danion, 2002).

The specificity of forward-model deficits to passivity symptoms is also doubtful. As can be seen in the previous section, many of the studies conducted that have investigated the forward model in schizophrenia did not differentiate their subjects based on the presence or absence of passivity symptoms. Further, forward-model deficits have also been found in people with schizophrenia differentiated on the presence of paranoid delusions and hallucinations, and formal thought disorder (Knoblich, Stottmeister, & Kircher, 2004).

Finally, although most studies have found deficient predictive processes in passivity symptoms, not all evidence supports this claim. One study using a task that assessed visuomotor adaptation in the absence of visual feedback demonstrated a seemingly intact ability of people with passivity symptoms \( n = 10 \) to adapt their motor responses (Fourneret, Franck, Slachevsky, & Jeannerod, 2001). 17 people with schizophrenia were found to have normal anticipatory components of smooth eye pursuits and were able to cease anticipation in response to external demands (Trillenberg et al., 1998). A study that investigated the experience of dysfluency by delaying the auditory feedback of self-produced speech found that people with passivity symptoms \( n = 10 \) reported higher levels of dysfluency than controls or people without passivity symptoms, indicating preserved forward model predictive processes (Goldberg, Gold, Coppola, & Weinberger, 1997).

1.7.4 Cognitive self-monitoring models

Another framework for describing the deficits of agency of schizophrenia is found in the cognitive self-monitoring models. Such models are related and can be seen to be complementary to the forward model; the forward model processes occur below conscious awareness and apply exclusively to motor prediction mechanisms while the processes that underlie cognitive self-monitoring are dependent upon higher cognition.
and lead to a conscious, explicit judgement of agency. Corresponding to this, the studies investigating cognitive self-monitoring models tend to use explicit judgements of whether events are self- or other-produced. According to cognitive models, such as ‘source monitoring’ models, there are dysfunctions in the processing of perceptual information and the evaluation of this information, which is used to make self/non-self (or internal/external) discriminations at the level of internal mental events (including thoughts and actions) and memories (Brébion et al., 2000; Brébion, Gorman, Amador, Malaspina, & Sharif, 2002; Brébion, Smith, Gorman, & Amador, 1996; Harvey, 1985; Hemsley, 1993; Keefe, Arnold, Bayen, & Harvey, 1999). These source monitoring processes typically engage memory and other decision-making processes that retrieve and evaluate memories in order to develop a cohesive, contextually-accurate representation of an experience. It has been proposed that such source-monitoring disturbance results in an incomplete representation of mental events, and consequently a failure to identify their origins (Waters, Badcock, Michie, & Maybery, 2006). According to some models, deficits in self-attribution are then either a direct result of the breakdown in these processes (Hemsley, 1993; Nayani & David, 1996; Waters et al., 2006) or via an indirect pathway in which faulty reasoning leads to erroneous decisions when making judgements about the origin of internal events (Bentall, 1990; Bentall & Slade, 1985; Harvey, 1985).

1.7.5 Criticisms of cognitive self-monitoring models

There are three major criticisms of the cognitive self-monitoring models as they pertain to passivity symptoms. Firstly, these models were originally proposed as a framework for hallucinations, and a recent meta-analysis revealed that source monitoring is particularly more pronounced in people with hallucinations, relative to other individuals with schizophrenia without hallucinations, raising questions regarding whether source-monitoring deficits are unique to hallucinations or to all positive symptoms (Waters, Woodward, Allen, Aleman, & Sommer, 2012).

Secondly, cognitive self-monitoring models do not fully capture the self-disturbances that are characteristic of passivity symptoms (see section 1.6.2 above and 1.7.6 below). Briefly, the phenomenology of passivity symptoms involves a distinct perceptual change in the experience of the self and of thoughts and actions that extend beyond retrospective judgements of agency. Finally, cognitive self-monitoring models do not consider other important somatic and sensory processes that are critical in developing a sense of self (Waters & Badcock, 2010).
1.7.6 ‘Self’ disturbances

The conceptualisation of schizophrenia arising from deficits in the fundamental sense of self has been somewhat revived in recent years. Drawing heavily from the phenomenology of schizophrenia, this conceptualisation states that passivity symptoms are at one end of the spectrum of fundamental changes in the subjective sense of self (Parnas, 2000, 2015; Parnas & Sass, 2001; Sass & Parnas, 2003). Sass & Parnas (2003) describe this disturbance in the basic sense of the self (“ipseity”) as having two components: “hyperreflexivity”, or the forms of exaggerated self-consciousness in which aspects of the self are viewed more akin as external objects, and “diminished self-affection” or a diminished intensity of the sense of one’s existence. In turn, the disorders of ipseity lead to diminished intentionality, the ability of the self to exist in the world and act upon objects in it, including the self (Hirjak et al., 2013; Parnas, 2000). These core disturbances of the self form basic symptoms that are expressed throughout the schizophrenia spectrum. These disturbances are first present in psychosis-like experiences (also known as positive schizotypy or psychosis proneness), phenomena that are phenomenologically similar to some symptoms of schizophrenia but do not reach the threshold to reach clinical significance (Meehl, 1962) and are believed by some to lie on the schizophrenia spectrum (Chapman, Chapman, Kwapis, Eckhlaad, & Zinser, 1994; Claridge, 1997; Claridge & Beech, 1995; Lenzenweger, 1994). The self-disturbances are also present in the prodromal period (Nelson et al., 2009; Nelson, Thompson, & Yung, 2012; Nelson, Yung, Bechdolt, & McGorry, 2008) and worsen during the disease progression. Importantly, this conceptualisation of schizophrenia has been supported by recent empirical research (Hirjak et al., 2013; Hur, Kwon, Lee, & Park, 2014; Moe & Docherty, 2014; Nelson, Whitford, Lavoie, & Sass, 2014a, 2014b; Postmes et al., 2014). According to this conceptualisation, passivity symptoms are the most elaborated form of self-disturbances (Jansson, 2015). As detailed in section 1.1.4, passivity symptoms typically reoccur in psychotic episodes throughout the course of a person’s illness (Jablensky et al., 1992). This indicates that there may be enduring, trait-like vulnerabilities that underlie these symptoms and can differentiate between people with and without passivity symptoms. As people with a vulnerability to passivity symptoms then progress to a psychotic episode, the worsened self-disturbances lead to a full manifestation of passivity symptoms. Altogether, it is reasonable to state that alterations in the sense of self contribute significantly to schizophrenia, and passivity symptoms in particular.
1.8 Body representations

1.8.1 A new model of passivity symptoms as body representation disturbances

A more recent conceptualisation of passivity symptoms describe passivity symptoms as a fundamental disturbance in body representations, neurological and cognitive constructs of one’s own body that play a critical role in the way the self is experienced (Waters & Badcock, 2010). This proposal was drawn from a wide variety of observations and evidence, including the following:

1. There are theoretical and philosophical issues and contradictory evidence in regards to disruptions of the forward model and cognitive self-monitoring models leading to passivity symptoms, as outlined in sections 1.7.3 and 1.7.5.

2. Neither the forward model nor the cognitive self-monitoring models adequately explain the extensive phenomenology of passivity symptoms involving thoughts, perceptions and emotions (Gallagher, 2004; Synofzik et al., 2008; Vosgerau & Newen, 2007).

3. Passivity symptoms have typically been described as a selective disorder of agency and it has been presumed that other self-representations, such as body ownership (“the sense that one’s body is the source of sensations”, p. 424; Tsakiris, Prabhu, & Haggard, 2006), are intact. However, the sense of agency and body ownership are not fully distinct and independent (Kircher & Leube, 2003; Legrand, Brozzoli, Rossetti, & Farne, 2007; Pacherie, 2007; Sadler, 2007) and others have even argued that the two should not be considered separate entities (H. L. Morgan, 2015). This view arises from evidence that agency and body ownership are dependent on the same spatial and temporal integration of multisensory signals and the maintenance of internal spatial body representations (Legrand, 2006; Synofzik, Thier, & Lindner, 2006; Tsakiris, Schütz-Bosbach, & Gallagher, 2007; van den Bos & Jeannerod, 2002).

4. Making agency judgements also involves an understanding that the object being moved or where sensations originate from is one’s body i.e. a judgement of ownership (Bulot, Thomas, & Delevoye-Turrell, 2007). This is reflected in the synergistic and highly interdependent effects of body ownership and agency upon one another (Gallagher & Cole, 1995; Kalckert & Ehrsson, 2012; Schwoebel, Buxbaum, & Coslett, 2004; Tsakiris et al., 2006; Tsakiris, Schütz-Bosbach, et al., 2007). Given this interdependency, it is possible that alterations of non-agency self-representations can induce changes in the sense of agency.
5. Lower level changes in sensory integration and/or sensory conflict are sufficient to produce marked changes in the experience of the self in healthy humans (Bulot et al., 2007), further emphasising the importance of general non-motor processes in the sense of self (van den Bos & Jeannerod, 2002).

6. There is strong phenomenological evidence that people with passivity symptoms have widespread changes in the sense of self (Cermolacce et al., 2007; Hirjak et al., 2013; Parnas, Handest, Jansson, & Sæbye, 2005).

7. There is evidence that body representations are altered in schizophrenia and preliminary evidence that body representations are disrupted more severely in passivity symptoms (see section 1.9 below).

8. In consideration of the above, it is therefore reasonable to hypothesise that there are widespread alterations in representations of the self that contribute significantly to the development of passivity symptoms.

There are two major distinctions that make this hypothesis novel. Firstly, in contrast to the emphasis on motor functions in the forward model, and the emphasis on deficits of generalised cognitive functions in the cognitive self-monitoring model, the body representation hypothesis emphasises alterations of a much broader range of perceptual, cognitive and psychological processes related to the experience of the self in the aetiology of passivity symptoms. Secondly, it has already been proposed that people with schizophrenia experience a reduced sense of intentionality, the subjective sensation that one is able to act as an independent agent (Sass & Parnas, 2003). The presence of broad body representation alterations in people with passivity symptoms may have wide-reaching changes in the experience of the self, leading to reduced intentionality and hence reduced agency over non-somatic processes, including thoughts and perceptions.

This conceptualisation of body representation disturbances as the core disturbance of schizophrenia and passivity symptoms would also be further supported with evidence of body representation disturbances in healthy people at high-risk of psychosis.

There are four major body representations that will be examined in this thesis: body schema, body image, body structural description and body agency. The definitions and major characteristics of each representation will be given, followed by summaries of the evidence supporting the neural pathways responsible for each representation, and methods used to assess the body representation. A summary of the evidence for the
distinction of each representation as a unique construct from studies of neurological patients can be seen in Table 1.2.

Table 1.2. Summary of neurological and lesion study evidence supporting the distinction of four body representations: body schema, body image, body structural description and body agency.

**Body schema**

<table>
<thead>
<tr>
<th>Disorder</th>
<th>Lesion site/s</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peripheral neuropathy/deafferentiation⁴</td>
<td>Polyneuropathy of large myelinated sensory fibres</td>
<td>A total loss of tactile, vibratory, pressure and kinaesthetic perception with a consequent loss of normal posture and movements.</td>
</tr>
<tr>
<td>Ideomotor limb apraxia²</td>
<td>Posterior parietal cortex, dorsolateral frontal lobe</td>
<td>Disorder of complex movement typified by spatiotemporal errors in tool use and gesture imitation and reproduction.</td>
</tr>
</tbody>
</table>

**Body image**

<table>
<thead>
<tr>
<th>Disorder</th>
<th>Lesion site/s</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blind touch / numbsense³</td>
<td>Left parietal cortex</td>
<td>Retained ability to physically locate stimuli on the body but no conscious awareness of experiencing those stimuli.</td>
</tr>
<tr>
<td>Unilateral hemineglect⁴</td>
<td>Right temporoparietal junction (TPJ), right inferior parietal lobule, right superior temporal gyrus</td>
<td>Intact ability to bilaterally coordinate limb movements but patients entirely neglect the contralesional side of their body, behaving as if the contralesional side of their body has disappeared from conscious awareness.</td>
</tr>
<tr>
<td>Somatoparaphrenia⁵</td>
<td>Right parietal lobe, particularly right TPJ</td>
<td>A belief that a limb or limbs do not belong to the self. Parts of the body do not fit the stored, long-term body image.</td>
</tr>
<tr>
<td>Asomatognosia⁶</td>
<td>Right premotor</td>
<td>Patients describe body parts as missing</td>
</tr>
</tbody>
</table>
cortex, right parietal cortex from conscious awareness. Retain insight (in comparison to neglect and somatoparaphrenia).

Semantic dementia (body-specific aphasia) 7

<table>
<thead>
<tr>
<th>Disorder</th>
<th>Lesion site/s</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left hemisphere atrophy</td>
<td>Specific impairments in naming body parts and their functions but not in other semantic categories such as objects or animals.</td>
<td></td>
</tr>
</tbody>
</table>

**Body structural description**

<table>
<thead>
<tr>
<th>Disorder</th>
<th>Lesion site/s</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autotopagnosia 8</td>
<td>Left posterior parietal cortex</td>
<td>Inability to describe relationship of body parts to other body parts or correctly locate body parts on the self or others. Preserved ability to name body parts and their functions as well as motor functions such as grip force and grip distance.</td>
</tr>
<tr>
<td>Finger agnosia 9</td>
<td>Left inferior parietal lobule</td>
<td>Bilateral inability to determine the position of fingers in relation to one another, using tactile stimulation without vision.</td>
</tr>
</tbody>
</table>

**Body agency**

<table>
<thead>
<tr>
<th>Disorder</th>
<th>Lesion site/s</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alien (anarchic) hand syndrome 10</td>
<td>Medial frontal lobe and anterior corpus callosum</td>
<td>Characterised by the alien limb acting autonomously, performing unintended movements that are inappropriate tool-utilisation behaviours and/or oppose movements from contralesional side.</td>
</tr>
<tr>
<td>Inhibitory single-pulse TMS 11</td>
<td>Right inferior parietal lobule, posterior parietal lobule</td>
<td>Incorrect agency attribution of self-made movements to another external agent.</td>
</tr>
</tbody>
</table>

1 (Gallagher & Cole, 1995; Paillard, 1999)

2 (Buxbaum, Giovannetti, & Libon, 2000; Jax, Buxbaum, & Moll, 2006; Schwoebel
1.8.2 Body schema

The body schema is a sensory representation that encodes the position and movement of the body and limbs in space according to an egocentric frame of reference, with the proprioceptive information being drawn from kinetic, tactile, muscular and vestibular modalities (Coslett et al., 2002; Gallagher, 2005; Gallagher & Cole, 1995; Paillard, 1999; Schwoebel & Coslett, 2005). There are three important features of body schema. Firstly, the representation is a dynamic, online representation that constantly updates the position of the limbs (as opposed to a stored, long-term representation). Secondly, body schema is a mostly unconscious representation that typically functions beneath conscious awareness (although conscious access is possible). Finally, the content of the body schema means that it is closely associated with the preparation, initiation and execution of actions (Buxbaum et al., 2000; Schwoebel et al., 2004). Lesion studies have identified various neural regions that underlie body schema (see Table 1.2). Functional neuroimaging has also delineated a network of neural regions that are activated during tasks that assess body schema, including the left secondary somatosensory cortex (SII)/parietal operculum (Corradi-Dell'Acqua, Tomasinoto, & Fink, 2009), intraparietal sulcus (Bonda, Petrides, Frey, & Evans, 1995; Ehrsson, Spence, & Passingham, 2004), inferior parietal cortex (Bonda et al., 1995; Parsons et al., 1995),
posterior parietal cortex and dorsolateral frontal lobe (Grezes & Decety, 2001; Parsons et al., 1995).

1.8.3 Body image

Body image refers to a conscious, top-down cognitive representation that integrates the perceived form of one’s body in terms of its unique characteristics (size, shape, colour etc.), one’s conceptual understanding of the body in general as well as one’s emotional attitude towards the body (Gallagher, 2005; Gallagher & Cole, 1995; Longo, Schuur, Kammers, Tsakiris, & Haggard, 2009). Other authors have also emphasised the importance of lexical and semantic information about the body to body image (Coslett et al., 2002; Schwoebel & Coslett, 2005). Another important feature of body image is embodiment; the perception that one’s self lies within the physical boundaries of the body (Arzy, Thut, Mohr, Michel, & Blanke, 2006); for a body part to embodied it must first be incorporated into the body image (Longo et al., 2009; Tsakiris & Haggard, 2005). Finally, body image also contains a long-term representation of what a body should look like, that is more resistant to short-term changes than body schema (Gallagher & Cole, 1995).

As with body schema, there is a distinct distributed network of neural regions associated with body image. In addition to the regions identified in table 1.2, both functional and structural brain imaging have identified activity in the ventral premotor cortex as important for body ownership (recognition of body part/s as belonging to the self; Ehrsson, Holmes, & Passingham, 2005; Ehrsson et al., 2004). The extrastriate body area (EBA) is important for the integration of multisensory body-related information (Arzy, Thut, et al., 2006; Astafiev, Stanley, Shulman, & Corbetta, 2004; Jeannerod, 2004) and the inferior posterior parietal lobule is known to integrate body parts into body image as well as the updating of the location of body parts (Ehrsson et al., 2005; Ehrsson et al., 2004; Kammers, Verhagen, et al., 2009). The right TPJ is also important for multisensory integration, embodiment and self–other distinction (Blanke & Arzy, 2005; Ruby & Decety, 2001; Vogeley & Fink, 2003). Finally, emotional processing of the body has been linked to the insular cortex (Dijkerman & de Haan, 2007).

1.8.4 Body structural description

Body structural description is a long-term, stored representation that describes the relationship of each body segment to each other within a whole body and the exact distances between the body parts, similar to a topological map of the body (Buxbaum &
Coslett, 2001; Corradi-Dell'Acqua, Hesse, Rumiati, & Fink, 2008; Rusconi, Gonzaga, Adriani, Braun, & Haggard, 2009; Schwoebel & Coslett, 2005; Sirigu et al., 1991). Unlike body schema and body image, the model of the body stored in body structural description is based upon allocentric coordinates (Corradi-Dell'Acqua et al., 2008; Corradi-Dell'Acqua et al., 2009; Rusconi et al., 2009). In contrast to body schema, body structural description contains a spatial representation of the body derived solely from visual input (Buxbaum & Coslett, 2001; Rusconi et al., 2009; Sirigu et al., 1991).

Evidence for the distinction of body structural description from body schema comes from functional neuroimaging studies that have established that neurons in the parietal cortices are activated during visual stimulation in the space surrounding a body part, unrelated to the posture or orientation of the body, (Bremmer et al., 2001; Grefkes, Weiss, Zilles, & Fink, 2002; Rusconi et al., 2014). This indicates that neural activity associated with visuospatial processing of body parts is independent of activity from somatosensory processing that would be maintained in the body schema (Rusconi et al., 2009).

There are two regions that have consistently been found to be active during tasks that assess body structural description. The first is the left superior parietal cortex (Corradi-Dell'Acqua et al., 2008; Corradi-Dell'Acqua et al., 2009; Felician et al., 2004) and the second is the left posterior intraparietal sulcus and angular gyrus (Bonda et al., 1995; Corradi-Dell'Acqua et al., 2009; Ehrsson et al., 2004; Le Clec'h et al., 2000; Rusconi et al., 2014). The implication of the left posterior parietal cortex in healthy controls closely mirrors the findings in neurological patients with autotopagnosia, who tend to have lesions of the left parietal cortex, particular of the posterior lobule (see Table 1.2).

1.8.5 Body agency

Body agency (commonly known as the sense of agency) is “the sense that I am the one who is causing or generating an action. For example, the sense that I am the one who is causing something to move, or that I am the one who is generating a certain thought in my stream of consciousness” (Gallagher, 2000, p. 15). Body agency arises from the interaction of sensorimotor processes, such as efferent motor commands and proprioceptive feedback, and higher-level social and contextual cues (Gallagher, 2012; Moore, Middleton, Haggard, & Fletcher, 2012; Synofzik et al., 2008). Generally, agency is not normally consciously attended to nor something that one is explicitly aware of (Gallagher, 2012). From a phenomenological point of view, it has been argued
that body agency forms an integral part of the basic sense of self (David et al., 2006; Gallagher, 2000, 2005; Haggard, 2005; Neisser, 1988; Newen & Vogeley, 2003).

The pre-supplementary motor area and supplementary motor areas are implicated with the planning and preparation of actions and execution of self-generated actions (Cunnington, Windischberger, Robinson, & Moser, 2006; Farrer et al., 2003; Farrer & Frith, 2002; Haggard & Clark, 2003; Haggard & Whitford, 2004; Lau, Rogers, & Passingham, 2006; Moore, Ruge, Wenke, Rothwell, & Haggard, 2010). The cerebellum is known to detect visuomotor discrepancies between intentions and consequences and to correct actions accordingly, below the level of conscious awareness (Blakemore & Sirigu, 2003). The posterior parietal cortex, particularly the right angular gyrus, (Chaminade & Decety, 2002; Farrer et al., 2003; Farrer et al., 2008; Farrer & Frith, 2002; Fink et al., 1999; MacDonald & Paus, 2003; Sirigu et al., 2004), the right TPJ (Farrer et al., 2008; Leube, Knoblich, Erb, & Kircher, 2003; Schnell et al., 2007) and the dorsolateral prefrontal cortex (Fink et al., 1999; Schnell et al., 2007; Slachevsky et al., 2001) are implicated in the conscious monitoring, detection and awareness of discrepancies between intended actions and their outcomes. Finally, the insular cortex is activated when there is perceived authorship over actions (Farrer & Frith, 2002; Sperduti, Delaveau, Fossati, & Nadel, 2011).

1.8.6 Interaction of body representations

As much evidence as there is for the delineation of body representations as separate constructs, this does not imply that each representation functions independently of the others; many authors have also stressed the interdependency of body representations and their interactions (e.g. Gallagher & Cole, 1995; Schwoebel et al., 2004; Tsakiris, Schütz-Bosbach, et al., 2007; Waters & Badcock, 2010). One procedure that has been widely used to assess the interaction of body representations is the rubber hand illusion (Botvinick & Cohen, 1998). In the rubber hand illusion, a fake hand (which will be referred to as the other hand from here) is placed 15 – 30 cm from the participant’s real hand, which is hidden from the participant’s sight. The two hands are then stroked, usually with paintbrushes, either synchronously or asynchronously. During asynchronous stroking, participants tend to not experience anything unusual. During synchronous stroking, many participants experience the illusion that the other hand is in fact their own hand, and that they can feel the strokes of the paintbrush through the other hand (Botvinick, 2004; Longo, Schüür, Kammers, Tsakiris, & Haggard, 2008). The rubber hand illusion assesses body image as, for a participant to
embodie the other hand as their own, the other hand must be integrated into the participant’s body image (Longo et al., 2009; Tsakiris & Haggard, 2005).

Using the rubber hand illusion, it has been demonstrated that bottom-up representations such as body schema can influence higher order representations (body image). For example, the illusion is resistant to the visual appearance of the other hand; the other hand can have or lack distinguishing characteristics that differ from the participant’s own hand (such as skin colour, jewellery or scars) and the participant will still experience the illusion (Armel & Ramachandran, 2003; Austen, Soto-Faraco, Enns, & Kingstone, 2004; Longo & Haggard, 2009). In this situation, the matching of visual with tactile spatial information from body schema overrides the long-term representation of the hand in the body image and the other hand is embodied into the body image.

Similarly, the top-down representations can alter lower order representations. When the other hand in the rubber hand illusion is rotated so it is posturally incompatible with the participant’s own hand (at a 90 or 180° rotation), the illusion is blocked (Austen et al., 2004; Ehrsson et al., 2004; Farne, Pavani, Meneghello, & Ladavas, 2000; Holmes, Snijders, & Spence, 2006; Pavani, Spence, & Driver, 2000; Tsakiris & Haggard, 2005). This occurs because the visual representation of the other hand does not match with the long-term representation of the hand in the body image, and so integration of basic proprioceptive and tactile information of that hand into the body image is prevented (for an in-depth discussion of the interaction of body representations during the rubber hand illusion, see Appendix I of this thesis).

Body schema and body structural description also have a strong interaction; measures of both are strongly correlated to performance of the imitation and production of meaningful and meaningless movements and it has been proposed that body structural description provides body schema with additional spatial information in situations where there is an absence of information that normally contributes to body schema (Schwoebel et al., 2004). A further example of an interaction is the effect of body agency on body image and body schema. The projected hand illusion (PHI) is a digitised variant of the rubber hand illusion where, instead of stimulation of a rubber hand, a video camera takes footage of the participant’s own hand and projects it onto a video screen in front of the participant (Ijsselsteijn, de Kort, & Haans, 2006; Kammers, Longo, Tsakiris, Dijkerman, & Haggard, 2009; Longo & Haggard, 2009; Shimada, Fukuda, & Hiraki, 2009; Shimada, Qi, & Hiraki, 2010; Tsakiris, Longo, & Haggard, 2010; Tsakiris et al., 2006). Tactile stimulation of a single finger in the projected hand
illusion causes proprioceptive drift in just that finger but active movements, such as tapping, of a single finger causes embodiment of the other hand and proprioceptive drift for the entire hand (Kalckert & Ehrsson, 2012; Tsakiris et al., 2006). Altogether, these interactions demonstrate the importance of the contribution of body representations to the sense of self and to agency.

1.9 Evidence for alterations of body representations in schizophrenia and passivity symptoms

1.9.1 Body schema

In regards to alterations of body schema in healthy people with psychosis-like experiences, the duration of right TPJ activation during own-body transformations, a measure of body schema, has been found to be positively correlated with both psychosis-like experiences and perceptual aberrations (Arzy, Mohr, Michel, & Blanke, 2007) and that performance on this task is negatively correlated with the increasing presence of psychosis-like experiences (Mohr, Blanke, & Brugger, 2006). Another popular measure that is purported to assess body schema is proprioceptive drift during the rubber hand illusion (Botvinick & Cohen, 1998). Proprioceptive drift is the shifting of the felt location of the participant’s own hand towards the other hand after synchronous stimulation (Botvinick & Cohen, 1998; Holmes et al., 2006; Tsakiris & Haggard, 2005; Tsakiris et al., 2006). Of three studies investigating the rubber hand illusion in healthy people with psychosis-like experiences (Asai, Mao, Sugimori, & Tanno, 2011; Germine, Benson, Cohen, & Hooker, 2013; Thakkar, Nichols, McIntosh, & Park, 2011), only Asai and colleagues (2011) found positive correlations between positive schizotypy and proprioceptive drift.

There is some evidence for alterations of body schema in schizophrenia. One task used to assess body schema is the hand laterality task (HLT; Parsons, 1987a, 1987b). In this task, participants are asked to make laterality judgements of a hand displayed on a screen at various rotations by mentally rotating their own hand to match the hand on the screen. As performance on the task is influenced by the same biomechanical restraints that restrict performed actions, the imagined movements on the task are dependent on the body schema (Parsons, 1994). De Vignemont and colleagues (2006) demonstrated that 13 people with schizophrenia, undifferentiated by symptoms, had impaired performance on the task compared to controls. People with schizophrenia also have impaired performance on the imagined movements of a visually-guided pointing task (Danckert, Rossetti, d'Amato, Dalery, & Saoud, 2002) and this
performance is particularly worse in people currently experiencing passivity symptoms (Maruff, Wilson, & Currie, 2003). However, the latter study did not differentiate the sample based on past history of passivity symptoms. Taken together, the results indicate a deficit of mental imagery of actions and, hence, body schema in schizophrenia but the specificity of that deficit to passivity symptoms is not clear.

1.9.2 Body image

As with body schema, there is preliminary evidence for alterations of body image in healthy individuals prone to psychosis and in schizophrenia. Increasing positive schizotypy in healthy controls is associated with higher ratings of questionnaire items detailing experiences of embodiment of the other hand during the rubber hand illusion (Asai et al., 2011; Germine et al., 2013; Thakkar et al., 2011). Three studies, all with clinical samples undifferentiated by symptom profile and with samples of 26 (undifferentiated by symptom profile, Peled, Ritsner, Hirschmann, Geva, & Modai, 2000), 19 (Peled, Pressman, Geva, & Modai, 2003) and 24 (Thakkar et al., 2011) people with schizophrenia, reported that people with schizophrenia experienced higher embodiment of the other hand during the illusion during the synchronous condition, compared to controls. It has also been established that the disturbances originate from cortical areas, particularly the parietal cortex, and it was proposed this cortical region is the origin of the alterations of body image (Peled et al., 2003).

A difficulty with using illusions, such as the rubber hand illusion, is that they induce a form of sensorimotor or temporal sensory conflict and so do not assess “usual” experience. Utilising a questionnaire that assesses experiences of bodily distortions in situ (Fisher, 1970), Priebe and Röhricht (2001) demonstrated consistent and stable body image disturbances, including a reduction in the perceived size of the extremities of the limbs, in people with schizophrenia (no symptom profile analysis) but not in depressive or anxiety disorders. This same study also found high instances of depersonalisation and boundary loss using the body distortion questionnaire. A later study by these authors also identified a subgroup of patients whose psychopathology was characterised by body image disturbances, including underestimation of extremity size, depersonalisation and boundary loss (Röhricht & Priebe, 2002). Overall, the evidence is indicative of body image alterations in schizophrenia, specifically an unstable body image that is typified by a subjective breakdown of the physical body, changes in the perceived size of body parts and a tendency to embody external hands despite multisensory conflict.
However, to the best knowledge of the author, no work has examined the specificity of body image alterations to passivity symptoms.

1.9.3 Body structural description

A task that has been developed to assess body structural description is the matching body parts by location task (Coslett et al., 2002; Schwoebel & Coslett, 2005; Schwoebel et al., 2001). A key feature of the matching body parts by location task is that it assesses body structural description on the scale of whole body parts and across large distances of the body. The in-between task has also been utilised to evaluate body structural description (Kinsbourne & Warrington, 1962; Rusconi et al., 2009; Rusconi et al., 2014; Rusconi, Walsh, & Butterworth, 2005). As the task requires participants to make judgements of which finger was stimulated and the number of fingers between the stimulated fingers, and hence the relationship between and spatial structure of the fingers, this task assesses body structural description (Rusconi et al., 2009). As the in-between task involves judgements of finger position, judgements are made on a smaller spatial scale and so require a greater acuity for accurate performance. To the best of the author’s knowledge, no study has assessed body structural description in schizophrenia, either in an undifferentiated sample, in passivity symptoms specifically or in healthy individuals with psychosis-like experiences. Given the role of body structural description in the production of actions as described earlier in section 1.8.5, it is feasible that alterations in body structural description also contribute to difficulties with agency in schizophrenia.

1.9.4 Body agency

Various studies have investigated abnormalities of agency in passivity symptoms, as has been described in section 1.7.2. Another important precondition for the experience of explicit agency (Ebert & Wegner, 2010) is intentional binding; this phenomenon is the subjective contraction of time that has elapsed between a voluntary action and its sensory consequences, but not involuntary or observed actions (Engbert, Wohlschläger, & Haggard, 2008), typically between assessed with the pushing of a button and a tone played through speakers or headphones (Haggard, Clark, & Kalogeras, 2002; for a recent review, see Moore & Obhi, 2012). Intentional binding is initiated by motor commands and so is a measure of the ability of motor commands to effect changes in other neural areas and behaviours (Moore et al., 2012; Moore & Obhi, 2012).
The relationship of psychosis-like experiences to intentional binding has not yet been investigated. One study has found that surprise (when a sensory consequence of an action occurs that is unpredicted) augments intentional binding and the degree of the effect of surprise is related to psychosis-like experiences in healthy individuals (Moore, Dickinson, & Fletcher, 2011). However, this study did not directly measure the association of psychosis-like experiences and the degree of intentional binding. Another study investigating 30 people with a putative psychotic prodrome found a numeric, but not statistically significant, increase in intentional binding in this group, compared to healthy controls (Hauser, Moore, et al., 2011).

No studies have been conducted in regards to intentional binding in people with passivity symptoms, to the author’s best knowledge. Three studies, with clinical samples of 8 (Haggard, Martin, Taylor-Clarke, Jeannerod, & Franck, 2003), 24 (Franck, Posada, Pichon, & Haggard, 2005) and 24 (Voss et al., 2010) participants, have investigated intentional binding in people with schizophrenia, undifferentiated by symptoms. These three studies found an increase in intentional binding (an even greater subjective contraction of time between a voluntary action and its sensory consequence) in people with schizophrenia compared to controls. These findings in intentional binding in schizophrenia seemingly contradict the studies described in section 1.7.2 as the findings of increased intentional binding indicate a strengthening of intentional processes in schizophrenia, while the studies in section 1.7.2 demonstrate that there is a weakening of intentional and predictive processes in passivity symptoms. Presumably, the passivity symptom profile of people with schizophrenia will produce a differential response on tasks assessing intentional binding.

One further feature of both the rubber and projected hand illusions is that participants typically agree with questionnaire statements indicating that they could have moved the other hand if they wanted and that they felt in control of the other hand during the illusion (Germine et al., 2013; Kalckert & Ehrsson, 2012; Longo et al., 2008). One study has found a positive association between ratings of items assessing feelings of agency over the other hand and positive schizotypy (Germine et al., 2013). As far as the author is aware, body agency has not been examined during the projected or rubber hand illusions in either schizophrenia generally or passivity symptoms specifically.
1.10 Research aims, methods and hypotheses

1.10.1 Aims

The main objective of this thesis was to assess the hypothesis that body representations underlie passivity symptoms by conducting a thorough assessment of body representations (body schema, body image, body structural description and body agency) in a sample of people with schizophrenia, clustered into subgroups based on the individual’s lifetime history of passivity symptoms, and in doing so determine which, if any, body representation alterations are general to schizophrenia and which are specific to passivity symptoms. Previous models (forward model and cognitive dysfunction models) propose very precise and specific deficits that could not provide a comprehensive explanation of passivity symptoms. By contrast, deficits in body representations encompass several levels of explanations (neurological, perceptual, motor and cognitive) and are therefore able to provide a more complete explanation of passivity symptoms.

As the majority of studies supporting the distinction of body representations have been performed in either university undergraduate samples or in neurological patients with focal lesions, a secondary aim was to validate the tasks used to assess body representations in a sample of healthy community-sourced controls and to assess the relationship of demographic and cognitive variables to body representations.

1.10.2 Tasks

**Body schema** was assessed using the HLT (% accuracy and response time) (Parsons, 1987a, 1987b).

**Body image** was assessed on the PHI with a questionnaire detailing the experiences of embodiment (of the ‘other’ hand) and disembodiment (of the person’s own hand) (Botvinick & Cohen, 1998; Longo et al., 2008; Tsakiris et al., 2006) during synchronous and asynchronous conditions, and on the body distortion questionnaire (depersonalisation, loss of boundary, large and small body parts subscales) (Fisher, 1970).

**Body structural description** was assessed using the in-between task (% accuracy) (Kinsbourne & Warrington, 1962) and matching body parts by location task (% accuracy) (Schwoebel & Coslett, 2005).

Finally, **body agency** was evaluated on the PHI with a questionnaire that assessed sense of agency (over the ‘other’ hand), and loss of agency (over the person’s
own hand); and using an intentional binding task (perceived time between an action and subsequent tone) (Engbert et al., 2008; Haggard et al., 2002).

1.10.2 Hypotheses

According to the conceptualisation that schizophrenia is a disorder characterised by self-disturbances generated by body representation alterations, and that passivity symptoms are the most elaborated form of such disturbances (Jansson, 2015; Sass & Parnas, 2003), the general hypothesis for this thesis was that the severity of body representation alterations would be greatest in people with schizophrenia who are currently experiencing passivity symptoms, followed by people with past (but not current) passivity symptoms, then people with schizophrenia without a history of passivity symptoms, and then finally healthy controls.

Specifically, these disturbances would manifest as i) more errors and a slower response time on the HLT, ii) a higher endorsement of questionnaire items pertaining to embodiment and disembodiment during the PHI and higher endorsement of the items on the subscales of the BDQ and iii) more errors on both the in-between task and matching body by location tasks. In relation to the intentional binding task, in light of the findings of impaired predictive processes, it was hypothesised that people with passivity symptoms would experience a reduction in intentional binding whereas people without passivity symptoms would experience an increase in intentional binding.

Finally, in the healthy control group, it was hypothesised that the presence of psychosis-like experiences would be associated with an increase in body representation alterations such that people would more positively endorse items assessing embodiment, disembodiment, agency over the image and loss of agency over own during the projected hand illusion and display a greater binding effect as assessed by the intentional binding task.
Preface to Chapter 2

In Chapter 2, the underlying psychometric structure of a variant of the rubber hand illusion (RHI), the projected hand illusion (PHI), was examined in a sample of healthy community controls. The rubber hand illusion (RHI) is the most common procedure used to assess body representation alterations, particularly body image and body schema. The experience of the illusion during the RHI is commonly assessed using a self-report questionnaire, on which a previous study has performed a psychometric analysis in a university undergraduate sample (Longo et al., 2008). In contrast to the RHI, the PHI involves projection of a live image of the subject’s hand onto a screen in front of them.

Two important factors necessitated the validation of the assessment of the PHI in a healthy sample using this questionnaire. Firstly, there are differences in the procedures between the RHI and PHI and so a difference in how the illusion is experienced in the PHI may exist. Secondly, most studies of the RHI have employed undergraduate university students, so the performance of healthy people who are age-matched to ‘typical’ clinical samples was examined. This provided us with the opportunity to examine the relationship of demographic variables to the illusion, as well as the assessment of psychosis-like experiences in a healthy sample, that are similar in some respects to symptoms of schizophrenia, albeit in a muted form.
Chapter 2 - The projected hand illusion: Component structure in a community sample, and association with demographics, cognition and psychotic-like experiences.


Abstract

The projected hand illusion (PHI) is a variant of the rubber hand illusion (RHI), and both are commonly used to study mechanisms of self-perception. A questionnaire was developed by Longo et al. (2008) to measure qualitative changes in the RHI. Such psychometric analyses have not yet been conducted on the questionnaire for the PHI. The present study is an attempt to validate minor modifications of Longo et al.'s questionnaire to assess the PHI in a community sample (n=48), and determine the association with selected demographic (age, sex, years of education), cognitive (Digit Span) and clinical (psychotic-like experiences) variables. Principal components analysis on the questionnaire data extracted four components: “Embodiment of ‘Other’ Hand”, “Disembodiment of Own Hand”, “Deafference” and “Agency”, in both synchronous and asynchronous PHI conditions. Questions assessing ‘Embodiment’ and ‘Agency’ loaded onto orthogonal components. Greater illusion ratings were positively associated with being female, being younger, and having higher scores on psychotic-like experiences. There was no association with cognitive performance. Overall, this study confirmed that self-perception as measured with PHI is a multi-component construct, similar in many respects to the RHI. The main difference lies in the separation of Embodiment and Agency into separate constructs, and this likely reflects the fact that the ‘live’ image of the PHI presents a more realistic picture of the hand and of the stroking movements of the experimenter as compared to the RHI.
2.1 Introduction

In the last 16 years, the Rubber Hand Illusion (RHI; Botvinick & Cohen, 1998) has received much interest as an experimental paradigm for investigating mechanisms of self-perception, which may be defined as the perception of one’s self, including thoughts and actions, as residing within the physical body (Arzy, Thut, et al., 2006). In the illusion, a fake hand is placed in front of a participant and stroked with a paintbrush while the participant’s real hand, out of their vision, is stroked simultaneously (synchronous condition). In many healthy individuals, this produces a striking illusory sensation of displacement of the felt location of one’s own hand, sensation of touch through the rubber hand, and ‘embodiment’ (or ‘ownership’) of the rubber hand, which refers to the sensation that the rubber hand belongs to one’s body (that the rubber hand is one’s own hand; e.g. Heed et al., 2011; Longo et al., 2008; Newport, Pearce, & Preston, 2010). Embodiment of the rubber hand arises from a combination of processes, including the correlation and reconciliation of conflicting temporal and spatial information from the visual and tactile systems, and from ‘visual capture’, or increased weighting of visual over tactile and proprioceptive stimuli (Holmes et al., 2006; Pavani et al., 2000; Rossetti, Desmurget, & Prablanc, 1995; C. Spence, Pavani, & Driver, 2000; Tipper et al., 1998). The RHI thus provides valuable insight into how multiple sensory modalities are integrated to contribute to self-perception.

The illusion can be abolished or diminished by introducing a temporal delay between brush strokes on each hand (asynchronous condition; Botvinick & Cohen, 1998). Given that embodiment of a body part requires synchronous input between sensory modalities such as touch and vision, introduction of such a delay between brush strokes is often sufficient to prevent the occurrence, or reduce the strength, of the illusion. This ‘asynchronous condition’ is often used as a comparison condition to the synchronous condition (Botvinick & Cohen, 1998; Shimada et al., 2009).

Qualitative changes in perception on the RHI are typically rated using a questionnaire administered at the end of each condition. In addition, quantitative shifts in perceived hand location can be measured with an intermanual pointing task, or by a verbal response. This measure, termed proprioceptive drift, is the change in the perceived location of the participant’s hand after stroking; It provides insight into internal adjustments to body perception that occur as a result of the integration of visual and proprioceptive information (Tsakiris & Haggard, 2005; Tsakiris et al., 2006).
several semi-dissociable elements (Coslett et al., 2002; de Vignemont, 2010; Kammers, Kootker, Hogendoorn, & Dijkerman, 2010), Longo and colleagues in 2008 devised a 27-item questionnaire to assess qualitative changes in the RHI to overcome the limited range of domains assessed by the original 9-item questionnaire (Botvinick & Cohen, 1998). A principal components analysis (PCA) was conducted to describe the underlying structure of the questionnaire as completed by 131 university students (75 females). Four major components were identified in each of the synchronous and asynchronous conditions; “Embodiment of the Rubber Hand”, “Loss of Own Hand” (describing a reduction in perception of and in the participant’s actual hand), “Movement” (sensations of the rubber hand and the participant’s hand moving closer together) and “Affect” (sensations of pleasantness and enjoyment of the illusion). A fifth component, “Deafference” (pins and needles or numbness in the participant’s hand) was identified in the asynchronous condition only. It was found that the first component, Embodiment, was further divisible into three subcomponents: Ownership (the rubber hand belonging to the participant), Location (feelings of the participant’s hand being in the location of the rubber hand) and Agency (a sense of control over the rubber hand). Further work has demonstrated that these components are dissociable and may be seen as partially independent (Kalckert & Ehrsson, 2012).

A common contemporary variant of the RHI includes a projection of the participant’s own hand onto a video screen embedded into a table, instead of the use of a rubber hand. This digital version also allows the introduction of a delay in image feedback. Similar to the RHI, the Projected Hand Illusion (PHI) creates the illusory sensation of dissociation of one’s hand from one’s body (Ijsselsteijn et al., 2006; Kammers, Longo, et al., 2009; Longo & Haggard, 2009; Shimada et al., 2009; Shimada et al., 2010; Tsakiris et al., 2010; Tsakiris et al., 2006). The PHI has the advantages of allowing precise timing of synchronous and asynchronous stroking, allowing a more convincing illusion. Despite a number of studies using the PHI (Ijsselsteijn et al., 2006; Kammers, Longo, et al., 2009; Longo & Haggard, 2009; Shimada et al., 2009; Shimada et al., 2010; Tsakiris et al., 2010; Tsakiris et al., 2006), the component structure of this digitised version has not been investigated. Therefore, the first objective of our study was to establish the component structure of the PHI in a community sample using Longo et al.’s (2008) questionnaire, subject to minor modifications in the wording (such that ‘rubber hand’ was replaced by ‘image on the screen’).

Given the lack of research on the association between individual characteristics of a general community sample and proneness to the illusion (RHI or PHI), the
secondary aim of the study was to identify sources of variation that contribute to individual differences in the experience of the illusion. This is important for establishing the properties of control samples to be used when examining the illusion in clinical populations.

The first demographic variable of interest was age. One study failed to find significant effect of age in young adults (age range 17 - 24; Dummer, Picot-Annand, Neal, & Moore, 2009). Other studies using the RHI found that children have more proprioceptive drift towards the rubber hand than young adults, but show little difference in ownership (Bremner, Hill, Pratt, Rigato, & Spence, 2013; Cowie, Makin, & Bremner, 2013). Similarly, Tajadura-Jiménez, Longo, Coleman, & Tsakiris (2012), using a face-illusion where participants viewed an image of another face being stroked simultaneously as their own, found that age (range 17 – 38) was associated with a decrease in endorsement of the ‘other’ face (analogous to embodiment ratings). In other words, increasing age was linked to a decrease in proneness to the face-illusion. This finding was explained as normal developmental changes in self-perception in younger adults to accommodate changes in appearance that occur in this age period. In sum, on the basis of available evidence, a reduction in proneness to the illusion with increasing age was expected, particularly in the domain of embodiment.

Mixed evidence exists regarding sex differences in illusion proneness, with one study showing that females are more likely to experience illusion than males (Longo et al., 2008) and another study reporting no sex differences (Dummer et al., 2009). As with much work on hand illusions, these studies were conducted on university undergraduates, and have yet to be extended to a community sample.

The association between cognition and hand illusions is also of significant interest. A particular domain of interest is that of attention. One hypothesis is that illusions may become more intense with increasing attentional focus (Sims, 1988), although experimental studies have failed to find any effect of attention in a mirror-based hand illusion (Holmes et al., 2006).

Finally, this study examined whether psychotic-like experiences (PLE) are linked to proneness to the illusion. PLE are phenomenologically similar to some symptoms of schizophrenia but do not reach the threshold of clinical significance (Meehl, 1962). The link between PLE and illusion proneness is of particular interest, because people with schizophrenia have fundamental deficits in self-perception (Sass & Parnas, 2003; Waters & Badcock, 2010); they are also more prone to hand illusions compared to healthy people (Peled et al., 2000) and have a quicker onset of the illusion
(Peled et al., 2003). Other work also suggests that individuals scoring high on measures of positive schizotypy report a stronger illusion than individuals scoring low on the same measures (Asai et al., 2011; Germine et al., 2013; Thakkar et al., 2011). In these studies, however, the 9-item questionnaire of Botvinick & Cohen (1998) was employed. The use of Longo et al.’s longer questionnaire thus would allow greater detailed examination of self-disturbances in individuals with high levels of PLE.

In summary, the overall objective of our study was to investigate the component structure the PHI in a community sample. We also examined the relationship of the illusion with demographic (age, sex, years of education), cognition (Digit Span), and clinical (psychotic-like experiences) variables.

2.2 Methods

2.2.1 Participants

Community individuals (24 males and 24 females) took part in this study. The sample size of 48 individuals is an acceptable size for PCA (de Winter, Dodou, & Wieringa, 2009; Sapnas & Zeller, 2002; Velicer & Fava, 1998). Their mean age was 46.0 years (SD=11.6, range=21-60). Participants were recruited through community advertising. Exclusion criteria for all participants included organic brain disease, substance-use disorder or a diagnosis of a schizophrenia-spectrum disorder or psychosis. Participants were screened for all major psychiatric disorders using the Mini-International Neuropsychiatric Interview (MINI). The study protocol was explained to all participants and written consent was obtained. Participants were reimbursed $30 for their time. The North Metropolitan Mental Health Service Human Research Ethics Committee approved the study.

2.2.2 Demographics

A questionnaire assessing age, sex, handedness, years of education and self-reported medical problems was administered to all participants.

2.2.3 Projected hand illusion

Participants sat in front of a custom-made apparatus with their hands resting on top of a table. Their right hand was hidden out of view behind a removable curtain. In front of them was a Fujistu 17” colour monitor embedded horizontally in the table, which displayed a live image of their right hand. The image was captured by an analogue 1/3” Colour Charged-coupled Device Camera (AVC-561, AVTECH, Taiwan)
and transmitted to the monitor via an analogue DelayLine (DL1B-5379, Ovation Systems Ltd., UK). The total delay in image transmission was <10 ms, much less than the 150 ms that is required to detect visuomotor delays (Blakemore, Wolpert, & Frith, 1999) and less than the 85-100 ms of video delay reported by other studies (Ijsselsteijn et al., 2006; Longo & Haggard, 2009; Shimada et al., 2009; Tsakiris et al., 2006). The image of the hand was displaced 15 cm to the left of the participant’s right hand. A tactile marker indicated where the participant’s right middle finger should remain for the duration of the experiment. A cloth was placed over the shoulder and upper arm of the participant such that their arm was obscured during each block.

2.2.4 Psychotic-like experiences questionnaire

This screen assessed the lifetime-experience of psychotic-like experiences (Jablensky et al., 2000) and consisted of six questions pertaining to delusional mood (1 item), delusions of control (1 item), persecutory delusions (2 items) and hallucinosis (2 items). The questions were rated on a 5-point scale ranging from 0 (never) to 4 (often). Ratings on each item were then summed for each participant, for a total possible score of 24 (PLE score).

The digit span (DS) provided a measure of attention span (forward span), and working memory (backward digit span), respectively (Lezak, Howieson, Loring, Hannay, & Fischer, 1995).

2.2.5 Procedure

Demographic information, forward and backward digit spans and the PLE questionnaire ratings were all collected before the illusion procedure. For the illusion, a paintbrush was used to stroke the participant’s right finger and hand at a rate of 1 – 2 brushstrokes/second, out of view, for three minutes. Participants were instructed to focus on the image of the hand on the monitor and on the sensation of the paintbrush on their hand. There were two conditions; in the synchronous condition, the video input to the monitor was instantaneous (apart from the <10 ms intrinsic delay of the system) and in the asynchronous condition, a delay of 500 ms was imposed on the video input. The order of presentation was counter-balanced across participants; participants were assigned a presentation order in a pseudorandom manner.

At the end of each condition, a questionnaire assessing the subjective experience of the illusion was administered. The items were rated on a 7-point Likert scale ranging from -3 (strongly disagree), 0 (neutral) to +3 (strongly agree). The 20-items were
obtained from Longo et al. (2008), including those items relating to the components termed Embodiment of the Rubber Hand, Loss of Own Hand, Movement and Deafference. The items in the Affect component were not included as these questions do not pertain to experiences elicited by the illusion. In the questionnaire, references to the rubber hand were replaced with “the image of my hand”. Item 12 was changed such that it read “I couldn’t have moved my hand if I had wanted”. Proprioceptive drift was also obtained by asking participants to indicate the ‘felt’ location of their middle finger. This was achieved by the participant moving a ruler with their left hand, with eyes closed, to where they felt their right middle finger to be. The distance from the middle finger was recorded (positive values indicated a location closer to the image of the hand). Two proprioceptive judgements were made; one before and one after the stroking period. Proprioceptive drift was calculated in cm by subtracting the pre-stroking judgement from the post-stroking judgement.

2.3 Results

The items means were very similar to those reported by Longo et al. (2008). The only major differences were that items 18, 19, and 20 were rated slightly lower in the current study.

2.3.1 Component structure of subjective experience of the illusion

All statistical analyses and figures were completed using the statistical software R (version 2.15.2; R Core Team, 2012); the PCA was performed with the package ‘FactorMineR’ (Husson, Josse, Le, & Mazet, 2013) and inferential statistics with the packages ‘nlme’ (Pinheiro, Bates, DebRoy, Sarkar, & the R Development Core Team, 2013) and ‘car’ (Fox & Weisberg, 2011). A single PCA was performed on the questionnaire data, including synchronous and asynchronous conditions together. Similar to Longo et al.’s (2008) analyses, varimax rotation was employed. Varimax rotation allows the use of component scores as dependent variables in later analyses as the components extracted are orthogonal (i.e., uncorrelated). The Kaiser-Myer-Olkin Measure of Sampling Adequacy was 0.79, indicating a sufficient sample size and factorability of items.

Through examination of the eigenvalues and scree plot, four components were extracted accounting for 67.0% of the observed variance. The first component accounted for 33.3% of the variance (items 1, 2, 4, 5, 6) and was termed Embodiment of Other Hand (‘Embodiment’).
Table 2.1 Component loadings, eigenvalues and variance from PCA performed on questionnaire data. Questions with no component loadings had values less than 0.32 (<10% overlap in variance) and were not interpreted as part of the component.

<table>
<thead>
<tr>
<th>It seemed like...</th>
<th>Embodiment</th>
<th>Disembodiment</th>
<th>Deafferecence</th>
<th>Agency</th>
<th>Communalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. ... I was looking directly at my own hand, rather than at an image.</td>
<td>0.40</td>
<td>0.18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. ... the image began to resemble my real hand.</td>
<td>0.35</td>
<td>0.13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. ... the image of the hand belonged to me.</td>
<td>0.11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. ... the image was my hand.</td>
<td>0.38</td>
<td></td>
<td></td>
<td></td>
<td>0.15</td>
</tr>
<tr>
<td>5. ... the image was part of my body.</td>
<td>0.40</td>
<td></td>
<td></td>
<td></td>
<td>0.16</td>
</tr>
<tr>
<td>6. ... my hand was in the location where the image was.</td>
<td>0.34</td>
<td></td>
<td></td>
<td></td>
<td>0.11</td>
</tr>
<tr>
<td>7. ... the image was in the location where my</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.09</td>
</tr>
</tbody>
</table>
8. ... the touch I felt was caused by the paintbrush touching the image.

9. ... I could have moved the image of the hand.

10. ... I was in control of the image.

11. ... I was unable to move my hand.

12. ... I couldn’t have moved my hand if I had wanted.

13. ... I couldn't really tell where my hand was.

14. ... my hand had disappeared.

15. ... my hand was out of my control.

16. ... my
hand was moving towards the image.

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<tbody>
<tr>
<td>17. ... the image was moving towards my hand.</td>
<td>0.48</td>
<td>0.23</td>
</tr>
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<tbody>
<tr>
<td>18. I had the sensation of pins and needles in my hand.</td>
<td>- 0.46</td>
<td>0.22</td>
</tr>
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<tbody>
<tr>
<td>19. I had the sensation that my hand was numb.</td>
<td>- 0.58</td>
<td>0.34</td>
</tr>
</tbody>
</table>

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<table>
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<th></th>
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<tbody>
<tr>
<td>20... the experience of my hand was less vivid than normal.</td>
<td>- 0.50</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Eigenvalues 6.65 3.82 1.72 1.21

% Variance 33.3 19.1 8.60 6.07 Total: 67.1%

This component contained items relating to the image feeling as if it was the participant’s own hand, feeling the touch of the paintbrush “through” the image (see Table 2.1).

The second component, termed Disembodiment of Own Hand (‘Disembodiment’), (items 13 – 17) accounted for 19.1% of the variance and described experiences of spatial ambiguity, and the experience of the participant’s own hand disappearing.

The third component, ‘Deafferece’, accounted for 8.60% of observed variance and items on this component (items 18 – 20) described a loss of sensation, or pins and needles, in the participant’s own hand.
In contrast to the other components, the items loading onto this component had negative loadings. Note that the “direction” of a component is not designated by the mathematics of the extraction itself, and the interpretation of the direction is up to the researcher (Tabachnick & Fidell, 2007). In this case, ratings of Deafference tended to be rated negatively when ratings of the other components were positive, and vice versa.

The fourth and final component, ‘Agency’, comprising 6.07% of the variance, described a sensation of control over the image and a loss of agency over the participant’s own hand (items 9 - 12). Note that the items addressed aspects of agency over both one’s own hand, and over the image, and thus addressed opposing concepts. Thus, negative endorsements on items 11 and 12 (indicating decreased control over own hand) is consistent with positive endorsement on items 9 and 10, indicating increased control over the image of the other hand. In summary, participants reported a sense of agency over both their own hand and the image of their hand.

As their Embodiment component accounted for nearly a quarter of observed variance, Longo et al., (2008) performed a secondary PCA on the questions comprising the Embodiment component, in order to dissociate a possible substructure. As the Embodiment component of the current study also accounted for a similar amount of variance (33%), a secondary PCA was performed. Using the same criteria for the eigenvalues and scree plot, only one component was extracted. That is, the Embodiment component was not divisible into further subcomponents.

2.3.2 Effect of delay condition and covariates on illusion

In previous hand illusion studies, items relating to embodiment were rated higher in the synchronous compared to the asynchronous condition (e.g. Longo et al., 2008). To examine for a condition-dependent effect on the current task, analyses were performed using one-way repeated-measures ANCOVA with component scores (or proprioceptive drift) as the dependent variable, delay condition (synchronous or asynchronous) as the independent variable and age, sex, years of education, PLE score, and FS scores as covariates. ANCOVA was used to account for individual differences in responses due to the covariates, and to get a description of the relationship between the covariate and the dependent variable. Repeated-measures ANCOVA takes into account the effect of the covariates on each level of the within-subject variables. Component scores are estimates of each individual’s score on each component as if each component was being measured directly, and were estimated using the regression approach (centred on zero).
ANCOVAs were subjected to step-wise model-selection, removing covariates that were not significant, to find the most parsimonious model and then tested for interactions between the covariates and independent variables; no significant interactions were found and so no interaction terms were included in the final models.

In order to assess the effect of the main independent variable (delay condition), on the overall illusion and to assess the relationship of each component onto the others, the first analysis performed assessed the illusion as a whole, including principal component as a within-subjects independent variable (Figure 2.1).

There was no significant main effect of component type ($F(3, 329) = 0.00, p = 1.00, \eta^2_G = 0.00$). Delay condition ($F(1, 329) = 1.06, p = 0.30, \eta^2_G = 0.03$) was also non-significant, although further analyses revealed a different pattern for response on each component (see below). There was a significant interaction between delay condition and component type ($F(3, 329) = 4.00, p = 0.008, \eta^2_G = 0.03$) (Figure 2.1). Additionally, a main effect of sex was observed ($F(1, 44) = 9.60, p = 0.003$) where the component scores for females were consistently higher than for males (Figure 2.2). To investigate this further, sex and component were included in a further ANOVA as independent variables.

Figure 2.1. Component scores for each of the components extracted from the PCA for synchronous (synch) and asynchronous (asynch) stimulation. Data are mean ± SEM.
variables. This ANOVA again found a main effect of sex ($F(1, 46) = 7.63, p = 0.008, \eta^2_G = 0.04$) as well as an interaction between sex and component ($F(3, 330) = 3.35, p = 0.02, \eta^2_G = 0.03$). Post-hoc pairwise t-tests indicated higher component scores on Embodiment in females compared to males ($p = 0.01$), but these were not significant for Disembodiment ($p = 0.51$), Deaff erence ($p = 0.80$) or Agency ($p = 0.51$). From these results, the component scores were not increased uniformly across all components between males and females.

There was a significant main effect of age ($F(1, 44) = 6.40, p = 0.04$, slope = -0.02), whereby increasing age was associated with a decrease in component scores of all components. Similarly, there was a main effect of PLE score ($F(1, 44) = 9.66, p = 0.003$, slope = 0.13), showing that an increase in PLE score was associated with an increase in component scores of all components (Figure 2.3). There was no significant association of years of education or DS in this ANCOVA (both $p > 0.05$).

To investigate what was driving the interaction in the previous ANCOVA, separate ANCOVAs were conducted for each component.

Embodiment: there was a significant main effect of delay condition on
embodiment scores \( F(1, 47) = 6.94, p = 0.01, \eta^2_G = 0.03 \) with embodiment scores higher in the synchronous than the asynchronous condition. Furthermore, there was a significant effect of sex \( F(1, 45) = 6.16, p = 0.02 \) with the embodiment scores higher for females than for males (Figure 2.2). There was a non-significant effect of PLE score \( F(1, 45) = 3.54, p = 0.07, \text{slope} = 0.25 \) and variables such as age, forwards or backwards digit span and years of education all failed to reach significance (all \( p > 0.1 \)). Our results showed that females rated Embodiment items higher than males but did not increase significantly with increasing PLE scores.

Disembodiment: there was a significant main effect of delay condition on disembodiment scores \( F(1, 47) = 14.7, p = 0.004, \eta^2_G = 0.05 \) with scores higher in the asynchronous condition (see Figure 2.1).

![Component scores for the Disembodiment component plotted against (A) the age of the participant and (B) total psychosis-like (PLE) score as assessed by self-report questionnaire. Dashed line represents linear relationship between (A) age and component scores and (B) PLE and component scores, extracted from repeated-measures ANCOVA.](image)

Furthermore, there was a significant effect of the covariate age \( F(1, 45) = 11.2, p = 0.002, \text{slope} = -0.07 \) and PLE score \( F(1, 45) = 7.68, p = 0.008, \text{slope} = 0.26 \). There were no other significant effects of covariates. Increased age was linked to a
decrease in Disembodiment component scores. In contrast, individuals with higher PLE scores tended to have higher Disembodiment scores (Figure 2.3).

Deafference: there was no main effect of delay condition on the Deafference scores ($F (1, 47) = 2.09, p = 0.15, \eta^2_G = 0.02$) or any of the covariates (not shown). From the results, Deafference appeared to be equally present in both delay conditions.

Agency: There was no main effect of delay condition on Agency scores ($F (1, 45) = 1.25, p = 0.27, \eta^2_G = 0.02$) or of the covariates (not shown). These results indicate that the ratings of Agency are not influenced by the delay condition.

Proprioceptive drift: there was no main effect of delay condition ($F (1, 47) = 1.33, p = 0.25, \eta^2_G = 0.01$). However, there was a significant effect of age ($F (1,46) = 10.4, p = 0.002$), slope = 0.07; increasing age was associated with an increase in proprioceptive drift (Figure 2.4). No other covariates were found to have a significant effect. It should be noted that one-tailed t-tests indicated that drift was significantly greater than zero in both synchronous ($t(47) = 6.92, p < 0.0001$) and asynchronous ($t(47) = 4.97, p < 0.0001$) conditions.

2.4 Discussion

The first objective of our study was to describe the component structure of the PHI in a community sample, as assessed using Longo et al.’s (2008) questionnaire. The component analysis revealed four components (Embodiment of Other Hand, Disembodiment of Own Hand, Deafference and Agency), across both synchronous and asynchronous conditions. As expected, the direction of scores differed for both conditions. We also examined the relationship between the experience of the illusion and demographics, cognitive, and clinical characteristics. Higher proneness to the illusion was linked to being female, a younger age, and to higher PLE scores. Each finding is now discussed in turn.

2.4.1 Component analysis

The principal component analysis of the PHI questionnaire revealed four components accounting for 67% of the observed variance. The first component was termed Embodiment of the Other Hand (‘embodiment’) and comprised items detailing sensations of the ‘other’ hand as belonging to the participant, and sensations of the real hand being in the location of the image. The second component, Disembodiment of Own Hand (‘disembodiment’), referred to items describing a loss of awareness of the participant’s real hand.
Items loading onto the third component, Deafference, described reduced sensations in the participant’s real hand, that is, sensations of numbness or pins and needles.

The final component, Agency, was composed of items that related to sensations of control over the image, and over the participant’s real hand. All the items represented in each of the four components appear to be appropriately characterised by the component labels. An important argument for the validity of this solution is that repeated analyses with different rotations (i.e. oblimin rotation) yielded highly similar solutions.

There was a main effect of delay on the Embodiment and Disembodiment components, but not for the Deafference and Agency component scores. The lack of effects of delay on Deafference replicates previous findings showing that Deafference is present in both synchronous and asynchronous conditions in hand illusions. For Agency, the lack of effects between conditions may be explained by looking at the raw questionnaire data, where there is in fact an increase in agency in the synchronous condition. The reason for the lack of effect in the component scores is likely due to the PCA process; the agency component contained the least variance and as such, the scaling of the component scores may have reduced an effect of the synchronous condition that was there.

Figure 2.4. (A) Proprioceptive drift for asynchronous and synchronous tactile stimulation. Data are mean ± SEM. (B) Proprioceptive drift plotted against age of participant. Dashed line represents linear relationship between age and proprioceptive drift, extracted from one-way repeated-measures ANCOVA.
**Embodiment of Other Hand:** This component comprised five items; four of which relate to feelings that the image was the real hand (items 1, 2, 4, 5), and one that stated that it felt like the participant’s hand was in the location where the image was (item 6). Our Embodiment component was comparable to the similarly-named component found by Longo and colleagues (2008), although only 5 items loaded onto the component in our study (rather than ten in Longo’s Embodiment). In contrast to their study, which found that embodiment was further dissociated by a secondary PCA into three subcomponents (Ownership, Location and Agency), the Embodiment component of the current study was not separable into further subcomponents upon a secondary PCA. The items comprising the Embodiment component in the current study related to the subcomponents of Ownership and Location found by Longo et al. (2008). Of these questions, only one (item 6) was related to the source or location of sensory input and it described participants feeling their own hand to be in the location of the image (i.e., the presence of one aspect of the illusion). This would seem a more accurate and relevant measure of the illusion than item 7 (it seemed like the image was in the location where my hand was), an item that did not load onto the Embodiment component in our study.

Like the RHI, the PHI produces an illusory sensation of an external object (in this case a video image) being a part of the body. Unlike previous studies that have indicated a separation of the ownership of the hand and the perceived location of the hand (Longo et al., 2008), the current psychometric analysis found that these two experiences of the body were part of the same component. This discrepancy between the current study and Longo et al., (2008) is possibly because only one item detailing the perceived location of the hand loaded onto the Embodiment component in the current study, as opposed to two items in the Longo et al., study, and so there were insufficient location questions to load onto a subcomponent.

**Disembodiment of Own Hand:** This contained five items relating to a sensation of spatial ambiguity and disappearance of the real hand. This component was also found in Longo et al., (2008) – termed ‘Loss of Own Hand’. This is the second study to confirm that the illusion induces experiences of a loss of the participant’s own hand that are different and independent from the ‘other’ hand. However, Longo et al. found that Loss of Own Hand and Embodiment components were both higher in the synchronous condition than the asynchronous condition, and it was suggested embodiment of the ‘other’ hand is achieved by suppressing embodiment of the real hand. In our study,
however, ratings of Disembodiment were greater in the asynchronous than synchronous condition. One possibility is that the PHI causes a greater dissociative effect on the ability to locate one’s hand than the more traditional design of the RHI which relies on a ‘prop’. Thus, the increased sensory conflict in the asynchronous condition over the synchronous condition (incongruent temporal input) caused greater perception of disembodiment. In support, anecdotally, it is our experience that participants in the current study reported that their hand became particularly difficult to localise after asynchronous stimulation. In addition, this is supported by findings in other clinical disorders, such as out-of-body-experiences, where incongruent sensory input can cause, or contributes to, the disembodiment of a body part that is still a part of the self (Blanke, Landis, Spinelli, & Seeck, 2004; Blanke & Mohr, 2005). It may be expected that sensory conflict is greater when the hand is more similar visually to one’s own hand, as in the PHI.

**Deafference:** The third component extracted from our questionnaire was Deafference; it consisted of three questions relating to a reduction in sensation from the participant’s own hand (items 18 - 20). This component was found in both of the delay conditions and there was no significant difference in component scores between synchronous and asynchronous stimulation. This component consisted of the same three items as the Deafference component described by Longo et al. (2008). However, in their study, deafference was only found in the asynchronous condition. It is possible that the differences between Longo et al. (2008) and the current study are due to the two PCAs performed in the former, and a single PCA performed in the latter. Our study findings are supported by a similar finding of reduced afference in both synchronous and asynchronous conditions by Germine et al. (2013) and Albrecht et al. (2011) in the RHI.

Longo et al., (2008) proposed that Deafference arises as a consequence of temporally-conflicting information. This is also supported by the current study, but we have shown that the presence of Deafference in the synchronous condition indicates the presence of a further conflict in the synchronous condition; this conflict is perhaps driven by the spatial conflict between the visual and proprioceptive coordinates of the hand.

The items assessing deafference have a clear use in hand illusions as a measure of sensory conflict. It is plausible that various clinical groups who experience changes in the experience of the illusion do so because of changes in the reconciliation of sensory conflict induced by the illusion, and this will be reflected in the ratings of
deafference; any attempts to thoroughly examine hand illusions should therefore include an assessment of deafference.

Agency: The final component extracted from the questionnaire data, Agency, consisted of items describing sensations of control over the image as well as control over the participant’s own hand (items 9 - 12). The component scores were not significantly different between synchronous and asynchronous conditions; this is similar to the finding of Longo et al. (2008). Where the component structure of the PHI differs from Longo’s structure of the RHI was that Agency was orthogonal from Embodiment. This may be due to the fact that slight movements of one’s own fingers were visible in the projected hand (although participants were asked to keep their hands still), whereas this information is absent when using a rubber hand. Observing the occasional finger twitch or accidental hand movement in the projected hand may confer greater feelings of agency over the image (as with a mirror image of one’s own body). Even in the absence of such movement, people have much experience with images of themselves, in mirrors, pictures and perhaps “home” videos. That is, there is a recognition that images of oneself are indeed reflections of oneself, while a rubber hand is recognised as separate object without reference to one’s own self, until the illusion is experienced. This leads to certain expectations, such as an expectation that the video image finger will move when one moves one’s own finger, which does not exist initially with an external object such as a rubber hand. These expectations likely lead to more initial agency with an image of one’s own hand than with a rubber hand or an image of another’s hand.

Together, these findings demonstrate that in situations where there is no explicit movement, and hence little opportunity for agency over actions to occur, the expectation of control is highly correlated with embodiment. However, as our current findings demonstrate, this relationship does not necessarily hold true when actions are possible and have been observed and/or when the object is an image of one’s own hand.

Interestingly, the experience of agency over the image loaded onto the same as agency over the participant’s hand. This is consistent with participant’s having an initial expectation that a real-time video image of their own hand will move as they move; there is initial recognition that image is associated with their own hand. This differs from the RHI, where one might expect that feelings of agency over the ‘other’ hand may be linked to a decrease in sense of agency over the real hand, similar to how...
embodiment of the ‘other’ hand is accompanied by disembodiment of the own hand (Albrecht et al., 2011; Ehrsson, 2009; Longo et al., 2008).

This separation of Agency and Embodiment is consistent with the findings of Kalckert & Ehrsson (2012), who found a double-dissociation of agency and embodiment in a version of the hand illusion that allowed for willed-movements of a finger of the rubber hand; incongruent postures of the rubber hand disrupted embodiment but not agency, and passive (as oppose to active) movements of the rubber hand disrupted sensations of agency but not embodiment. Functional imaging evidence also supports a distinction in the neural pathways responsible for embodiment (Gentile, Petkova, & Ehrsson, 2011) and agency (Leube et al., 2003; Spengler, von Cramon, & Brass, 2009). Our findings therefore provide further psychometric evidence for this distinction.

2.4.2 Age and the illusion

Our study found evidence that the perception of the hand illusion decreases with age. Specifically, increasing age was associated with a decrease in ratings of the illusion on the four component scores. One possibility is that increasing age may be linked to a bias towards rating items lower. Evidence against this suggest is provided by Tajadura-Jiménez et al., (2012) who found effects of age only on embodiment ratings, and not across all items, as would be expected if a bias was at play. These authors suggested instead that people in late adolescence and early adulthood are more likely to display flexible self-perception, compared to later age-periods, as there is greater change in appearance and so a greater need for flexibility in self-perception during young adulthood (Tajadura-Jiménez et al., 2012).

An alternative explanation is that the decrease in the illusion associated with age may be due to a Bayesian or associative learning mechanism that contributes to self-perception. In Bayesian conceptual frameworks, two or more perceptions are experientially bound when they co-occur with a high probability (determined by spatial and temporal congruency), which is determined in part by the prior probabilities of one’s history of perceptual experiences, to give a posterior probability of the perception of the ‘other’ hand as one’s own hand (Albrecht et al., 2011; Armel & Ramachandran, 2003; de Vignemont, 2010). With increasing age, there is ever increasing experience of the spatial and temporal properties of stimuli matching, and this in turn will decrease the prior probabilities of two spatially-incongruent perceptions as originating from one’s own hand, reducing the likelihood of experiencing the illusion.
2.4.3 Proprioceptive drift

It was once assumed that drift and embodiment were synonymous, and indeed the two are positively correlated under most conditions. However, recent studies show that embodiment can be induced without proprioceptive drift and vice versa (Holle, McLatchie, Maurer, & Ward, 2011; Kammers, Longo, et al., 2009; Rohde, Di Luca, & Ernst, 2011), raising questions regarding both the mechanistic processes, and functional role, of drift in body illusions. The current dissociation of the effects of age on embodiment and proprioceptive drift reinforces the idea that these are two separate phenomena. Given the questionnaire items (embodiment) assess the subjective awareness of the body (assess the subjective feelings of feeling the brush strokes through the image and the sensation the image is the real hand), it may be argued that this is a more reliable indicator of the illusion.

The importance, and the most appropriate measurement, of proprioceptive drift in experimental studies is currently under debate. Here, proprioceptive drift in both stimulation conditions was significantly different from zero. This means that drift was present, but equal, in both conditions. Given that the standard deviations of the current study are similar to other related studies (Kammers, Longo, et al., 2009; Shimada et al., 2009; Thakkar et al., 2011; Tsakiris et al., 2006), and that the findings replicate the results of Thakkar et al., (2011), we see this as a true effect (i.e., no difference between stimulation conditions).

2.4.4 Age and proprioceptive drift

In contrast to a decrease in embodiment with increasing age, age was linked to an increase in proprioceptive drift. Additionally, there was no significant difference between proprioceptive drift and delay conditions in the current study, a finding also reported by Thakkar and colleagues (2011) in a similarly-aged control group (mean age of 41). It is well-established that there is a gradual deterioration of proprioceptive acuity with increasing age, particularly with the non-dominant hand (Adamo, Alexander, & Brown, 2009; Goble, Coxon, Wenderoth, Van Impe, & Swinnen, 2009). In order to compensate for such reduction in proprioceptive judgements, hand movements may become more reliant on visual input, which is a modality with greater spatial acuity (Cressman, Salomonczyk, & Henriques, 2010). A greater reliance on visual cues for localising the hand associated with ageing, regardless of synchronous input, would explain both the increase in proprioceptive drift and the high amounts of drift in both
synchronous and asynchronous conditions. Further, insofar as the RHI and PHI are similar in regards to proprioceptive drift, the findings of Cowie et al. (2013) and the current study suggest that visual capture on the perceived location of limbs follows a U-shaped curve with age, reaching a minimum around late adolescence/young adulthood.

2.4.5 Relationship of sex to the illusion

The current study found that females rated items on the questionnaire higher than males in this community. This replicates the finding of both Longo et al. (2008) and Egsgaard, Petrini, Christoffersen, & Arendt-Nielsen (2011). However, post hoc comparisons indicated that females scored significantly only on the Embodiment component. This indicates that the sex effect was not a global increase in positive response by females but rather was selective to Embodiment.

The difference in the ratings of the illusion displayed by females may be related to differences in visual selective attention. For example, females (but not males) had a faster response to embodiment during the RHI (Egsgaard et al., 2011). This was also linked with a shorter latency of activation of the cingulate cortex in females, an area associated with control of visual selective attention (Li, Yao, & Yin, 2009). Indeed, an ability to focus on the visual input of the ‘other’ hand, while suppressing attention to/of conflicting modalities, could lead to the visual information receiving a greater weighting when determining the location of the hand and a stronger illusion.

A further feature of interest was the apparent bimodality of the Embodiment component scores in males. We investigated possible associations with the other variables such as age but found no significant differences. The apparent gap in the scores is only approximately 1 unit, and the standard deviation for males on embodiment is 2.74. Given that there were no significant associations and the difference is less than one SD, it would seem that the apparent bimodality is due to random sampling error.

2.4.6 Cognitive functioning

The current study found no association of attention or working memory, as assessed with the Digit Span forward and backward respectively, with the four components (Embodiment, Disembodiment, Deafference, Agency or proprioceptive drift), extending previous work (Holmes et al., 2006). It is possible however that lower level processes required for sensation and perception, such as visual selective attention may be involved.
2.4.7 Psychotic-like experiences

The current study showed that higher PLE scores were linked to an increase in questionnaire ratings. These results extend previous findings on measures of schizotypy (Asai et al., 2011; Germine et al., 2013; Thakkar et al., 2011). Germine et al. (2013) reported that positive, but not negative, schizotypy was associated with increased ratings of embodiment, but only in the synchronous condition. They concluded that this indicated an actual increase in the experience of the illusion in those with greater levels of schizotypy. By contrast, both the current study and Thakkar et al. (2011), found an association of PLE with higher ratings across both synchronous and asynchronous conditions.

There is some evidence to suggest that increased PLE confers an increased susceptibility to hand illusions. Firstly, Germine et al. (2013) found that increased PLE scores were associated with embodiment of the ‘other’ hand but not with other measures of the illusion such as proprioceptive drift or reduced afference. Secondly, Albrecht et al. (2011), found that healthy volunteers administered the indirect dopamine agonist dexamphetamine reported stronger illusions (particularly, on Embodiment and Loss of Own Hand), but did not rate other measures, such as deafference, higher. There is a well-established association of increased dopamine transmission with schizophrenia-spectrum disorders, including increased dopamine binding in neural pathways associated with the development of psychosis in people with PLE (Gray et al., 1994; Soliman et al., 2007). The manipulation of a neurotransmitter pathway strongly implicated in schizophrenia-spectrum disorders resulting in changes in self-perception consistent with those seen in people with PLE is supportive evidence that PLE are associated with a stronger illusion.

People with PLE are thought by some (Claridge, 1997; Claridge & Beech, 1995) to lie on a continuum of psychosis from the absence of psychotic-like experiences, to subclinical manifestations of PLE, to clinically relevant psychosis. It is already known that people with schizophrenia are more susceptible to the illusion (Peled et al., 2003; Peled et al., 2000); the current results demonstrate that people with subclinical PLEs also report a stronger illusion. Typically, symptoms of schizophrenia-spectrum disorders have been divided into positive- and negative-syndromes (e.g. Crow, 1985). The results of the current previous studies (Asai et al., 2011; Germine et al., 2013; Peled et al., 2003; Peled et al., 2000; Thakkar et al., 2011) demonstrate that an increased susceptibility to hand illusions may be a correlate of disturbed self-perception in PLE,
beyond the usual classification of positive and negative symptoms. Indeed, deficits in self-processing have been proposed to be the core deficit in schizophrenia (Nelson et al., 2009; Sass & Parnas, 2003). Tasks that directly assess self-perception, such as hand illusions, can provide further insight into the nature of such deficits.

2.4.8 Rubber hand illusion vs. projected hand illusion

The current study provided an opportunity to contrast the fundamental nature of the PHI relative to the PHI. The illusion is the same – that is, the subjective perception that the “other” hand is in fact the participant’s own hand, and the reporting of sensations of the stroking through the “other” hand, are experienced in both illusions. However, there are key differences in methodologies – with one study presenting a fake, rigid, unmoving, shape-like hand and the other presenting a dynamic-looking and lifelike image of one’s real hand – which are sufficient to warrant a psychometric study to determine if these stimulus differences contribute to different body experience associated with the illusion. Our results found that Embodiment and Agency were separate components, in contrast to the RHI where Agency is a sub-component of Embodiment. This makes sense given that the sense of agency is not easily perceived in a ‘wooden’ and static object. The clinical implication of this finding is that the sense of agency as a component of body perception is better assessed - and better manipulated – using the PHI. The final difference between the two studies was that questions relating to the Affect component were not included in the current study as these items do not assess perceptual experiences induced by the illusion. Overall, the PHI is an experimental paradigm that allows the assessment of multiple dissociable elements of body perception, and which allows better precise timing of synchronous and asynchronous stroking, and a more convincing illusion than the RHI.

2.4.9 Conclusions

Psychometric analysis of a hand illusion in a community sample demonstrates that self-perception during the illusion is divisible into multiple components that are common to both synchronous and asynchronous conditions. These components are Embodiment of the ‘Other’ Hand, Disembodiment of Own Hand, Deafference and Agency. Of particular importance, the current study found Agency as a separate component using an illusion protocol that may have more ecological validity than the RHI, providing further evidence for the distinction between these two aspects of self-perception. Although not identical, the component structure of the current study is
similar to that of Longo et al., (2008), and the partial replication of their results reinforces the role of embodiment and agency in self-perception. Finally, it was also found that age, sex and lifetime experience of psychotic-like experiences are important covariates that partially account for some of the variance seen in our community sample. The association of PLE with a greater susceptibility of the illusion suggests this is a correlate of self-perception deficits that are a key feature of schizophrenia-spectrum disorders.

Acknowledgements

This research was supported by National Health and Medical Research Grant 634328. We would like to thank Assen Jablenksy, Milan Dragovic and Joanna Badcock for their early comments in an application for funding, Philippa Martyr for her help in recruiting participants and Laura Firth and Nazim Khan for their invaluable advice and guidance with statistics.
Preface to Chapter 3

In chapter 2, the assessment of the PHI using a self-report questionnaire was validated in healthy controls, and an appropriate division of the questions into subscales (Embodiment, Disembodiment, Agency over the Image, Loss of Agency over Own Hand) was determined. The aim of the chapter 3 was to use this task in people with schizophrenia (with and without passivity symptoms) to assess body image and body agency.

Given the findings of chapter 2 that proprioceptive drift during the PHI is not a reliable measure of body schema, the HLT was utilised to accurately assess body schema.

To determine if body representation disturbances were a trait feature of passivity symptoms or are a more general feature of schizophrenia, the cohort of people with schizophrenia were assessed for both lifetime and current history of passivity symptoms. It was hypothesised that people with a current experience of passivity symptoms would have the greatest alterations of body representations (highest endorsement of items indicating embodiment of the other hand, disembodiment of the own hand, feelings of agency over the other hand and loss of agency of own hand, and more errors and longer response time on the hand laterality task), followed by people with a past history of passivity symptoms, people with schizophrenia with no history of passivity symptoms and then healthy controls.
Chapter 3 - Deficits in agency in schizophrenia, and additional deficits in body image, body schema and internal timing, in passivity symptoms


Abstract

Individuals with schizophrenia, particularly those with passivity symptoms, may not feel in control of their actions, believing them to be controlled by external agents. Cognitive operations that contribute to these symptoms may include abnormal processing in agency, as well as body representations that deal with body schema and body image. However, these operations in schizophrenia are not fully understood, and the questions of general versus specific deficits in individuals with different symptom profiles remain unanswered. Using the projected hand illusion (a digital video version of the rubber hand illusion) with synchronous and asynchronous stroking (500 ms delay), and a hand laterality judgment task, we assessed sense of agency, body image and body schema in 53 people with clinically stable schizophrenia (with a current, past, and no history of passivity symptoms) and 48 healthy controls. The results revealed a stable trait in schizophrenia with no difference between clinical subgroups (sense of agency), and some quantitative (specific) differences depending on the passivity symptom profile (body image and body schema). Specifically, a reduced sense of self-agency was a common feature of all clinical subgroups. However, subgroup comparisons showed that individuals with passivity symptoms (both current and past) had significantly greater deficits on tasks assessing body image and body schema, relative to the other groups. In addition, patients with current passivity symptoms failed to demonstrate the normal reduction in body illusion typically seen with a 500 ms delay in visual feedback (asynchronous condition), suggesting internal timing problems. Altogether, the results underscore self-abnormalities in schizophrenia, provide evidence for both trait abnormalities and state changes specific to passivity symptoms, and point to a role for internal timing deficits as a mechanistic explanation for external cues becoming a possible source of self-body input.
3.1 Introduction

In the field of cognitive neuroscience, the ‘sense of self’ refers to a complex introspective representation that is derived from the integration of cognitive, sensory and motor signals, and which forms an intermittently interrupted “stream of consciousness”, making a life-long single narrative (Albrecht, Graham, Martin-Iverson, & Waters, 2012). In this context, a subjective experience of ‘self’ is drawn, at least in part, from information gained from body and motor senses. Self-abnormalities in schizophrenia have long been documented in the clinical literature. Kurt Schneider noted that symptoms described “a loss of the very contours of the self” (Schneider, 1946), and Bleuler (1911) described the tearing apart or splitting of psychic functions. Such self-abnormalities appear to be characteristic of schizophrenia (Parnas, 2000; Sass & Parnas, 2003), and are particularly pronounced in passivity symptoms (experience of alien control), where individuals do not feel in control of their movements and believe that their actions and intentions are controlled by an external agent. In passivity symptoms, the primary experience is that of a perceptual change regarding how the self is experienced, alongside the subjective experience of an external locus of control for internally-generated events.

A contemporary model suggests that such abnormalities arise from a failure in the mental operations responsible for predicting the sensory consequences of intended motor commands (the forward model), where the brain ‘anticipates’ an action taking place (Feinberg, 1978; Frith, 1992, 2005). Cognitive self-monitoring models, by contrast, have explained the observed self distortions as a failure of higher order cognitive processes, typically memory and other decision-making processes, that retrieve and evaluate memories in order to develop a cohesive, contextually-accurate representation of an experience (Bentall, Baker, & Havers, 1991; Wegner, 2003). It is becoming clear, however, that these proposals are not adequate or sufficient as theoretical frameworks for motor passivity symptoms (Gallagher, 2004; Synofzik et al., 2006). Criticisms include that motor commands are neither necessary nor sufficient to engender a sense of agency, and that post-hoc inferences and biases cannot fully account for pervasive changes in self-experience and self-awareness reported by people with schizophrenia. In support, structured clinical interviews using a clinical-phenomenological approach demonstrate fundamental changes in embodied self-presence, self-experience and self-judgment in individuals with schizophrenia (Parnas, Handest, Sæbye, & Jansson, 2003) and in those at high risk of psychosis (Nelson et al., 2008). In addition, disruptions in the forward model should precipitate gross motor
problems in people with schizophrenia, for which there is contrary evidence (Delevoye-Turrell et al., 2002; Synofzik et al., 2008).

3.1.1 Body representation distortions as an alternative framework for explaining self-abnormalities in schizophrenia

A focus on purely motor or cognitive mechanisms fails to consider other somatic and psychological processes that are necessary prerequisites for a coherent sense of self. It was recently suggested that self-deficits in schizophrenia may be better described as broad deficits in body representations that extend beyond self-agency (Waters & Badcock, 2010). This proposal was drawn from evidence showing that the self emerges from the concurrent activation of multiple body representations which are derived from multimodal sensory input as well as motor monitoring sources, and that are based on anatomical and neural networks which play a critical role in one’s sense of self. Body representations are intrinsically linked to one’s sense of awareness, identity, self-concept and sense of uniqueness. They are needed for the differentiation of body parts and for the accurate performance of purposeful actions.

A general framework for conceptualizing body representations includes at least two important representations: body image and body schema. Body image refers to a top-down cognitive representation that integrates the conscious perceptual experiences of one’s body and contributes to one’s belief and attitude about one’s body (Coslett et al., 2002; Gallagher, 2005; Holmes & Spence, 2007; Paillard, 1999; Schwoebel & Coslett, 2005). Body schema is typically defined as an unconscious dynamic sensory representation that reflects the position and movement of the body and limbs in space (Coslett et al., 2002; Gallagher, 2005; Paillard, 1999; Schwoebel & Coslett, 2005). The validity of these body representations is supported by studies of neurological patients, where localized lesions can selectively impair one or more representations (Arzy, Overney, et al., 2006; Biran & Chatterjee, 2004; Biran et al., 2006; Coslett, 1998; Wolpert et al., 1998), and from brain imaging studies pointing to differential activation of neural networks on tasks selective for each body representation (Ehrsson et al., 2005; Ehrsson et al., 2004; Farrer & Frith, 2002; Lau, Rogers, Haggard, & Passingham, 2004; Tsakiris et al., 2010). Finally, for the purposes of the current study, the sense of agency is defined as the experience that one is the initiator, and in control of, one’s actions. The sense of agency is different from body representations as it is critically dependent on actions and intentions (Blakemore & Frith, 2003; Gallagher, 2007; Haggard, 2005).
3.1.2 Body representation distortions in people with schizophrenia

As detailed previously, people with schizophrenia have difficulty in correctly attributing agency to self-made movements (Synofzik et al., 2010; Voss et al., 2010), indicating distortions in agency. There is also emerging evidence for disturbances of these multiple body representations in schizophrenia. For example, empirical findings point to difficulties imagining movements (Maruff et al., 2003), suggestive of deficits in body schema. People with schizophrenia also have abnormal body image, as assessed using a body distortion questionnaire (Priebe & Röhrich, 2001). From these findings, it would appear the internal modelling of the self is weakened or more malleable in people with schizophrenia.

The question of general versus specific deficits in individuals with different symptom profiles, however, has not yet been addressed. Specifically, are these body representation-deficits present in all individuals with schizophrenia, or only those with passivity symptoms? According to the philosophical-theoretical tradition of self-disturbances in schizophrenia (Sass & Parnas, 2003), passivity symptoms represent the more severe and elaborated form of self-disturbances in a continuum from non-psychotic experiences through intermediate phenomena into the manifest psychotic symptoms. Individuals then transit back and forth between manifest psychosis and the intermediary forms as their clinical condition changes over time. According to this view, there should be quantitative differences between people with passivity symptoms compared to individuals with a history of these symptoms, and individuals with no lifetime history of passivity. The performance of individuals with schizophrenia with different symptom profile was therefore of interest in the current study.

3.1.3 Assessing body representations in the current study

Body illusions, such as the rubber hand illusion, are frequently used to examine processes underlying self-recognition. In the rubber hand illusion, participants watch a fake hand being stroked, while their own hand is synchronously stroked out of view. This produces an illusory sensation of ownership of the rubber hand, and a shift in perceived hand location towards the fake hand (asynchronous condition; Botvinick & Cohen, 1998). A key requirement of the illusion is that of synchronous input between sensory modalities (tactile and vision). In the asynchronous condition, the illusion can be abolished or diminished by introducing a temporal delay between brush strokes and visual feedback (Botvinick & Cohen, 1998). This condition allows an examination of the effects of a timing delay on each type of body representation.
People with schizophrenia tend to experience the rubber hand illusion more strongly (Peled et al., 2000; Thakkar et al., 2011), and faster (Peled et al., 2003), compared to healthy controls. Additionally, the relocation of the perceived position of one’s own hand towards the image (‘proprioceptive drift’) has been shown to be greater in people with schizophrenia than controls, indicating stronger visual capture of proprioceptive information (Thakkar et al., 2011). The projected hand illusion, however, has not yet been reported in the schizophrenia literature. The projected hand illusion uses a live video image of the participant’s own hand projected onto a video screen, allowing a more realistic image of the hand than the traditional ‘rubber hand’ methodology, more precise control over the timing of brush strokes, as well as enhanced merging of reality into the illusion.

This task assesses two aspects of the sense of self in one experimental set-up. Using a post-performance questionnaire, body image can be assessed on domains of ‘embodiment (of the ‘other’ projected hand)’ and ‘disembodiment (of one’s own hand)’, and the sense of agency with the subjective sensation of motor control (over both the ‘other’, and own, hand). Psychometric studies show that illusory sensations over the ‘other’ hand are simultaneously associated with a reduction of the same sensations in the real hand (Longo et al., 2008). For example, embodiment of the ‘other’ hand is proportionally related to disembodiment of one’s real hand, with the total embodiment of both being equal to one single hand (Albrecht et al., 2011; Ehrsson, 2009). A similar balance also exists with the sense of agency (K. T. Graham, Martin-Iverson, Holmes, & Waters, 2015). Disembodiment (of limbs), and reduced agency (over actions), are clinical features of persons with passivity symptoms, so performance on such measures are of particular interest.

In order to assess the 3rd type of body representation (body schema), the current study employed the hand laterality task (Parsons, 1987b). In this task, participants are asked to make a judgment regarding whether an image of a hand is that of a right or left hand by mentally rotating their own hand to match the hand on the screen. Both response times and accuracy are recorded. Evidence that imagined movements are dependent upon the body schema include findings that performance on this task is influenced by the same biophysical constraints that underlie performed actions (Parsons, 1994). A recent study shows that schizophrenia individuals (n = 13) were impaired on the task (de Vignemont et al., 2006), although an analysis of passivity symptoms was not conducted.
3.1.4 Aims & hypotheses

In the current study, we studied body representations in 53 individuals with schizophrenia and 48 healthy controls on the validated projected-hand illusion (Ijsselsteijn et al., 2006; Tsakiris et al., 2006) and the hand laterality task (Parsons, 1987b). Individuals with schizophrenia were clustered into subgroups based upon their lifetime history of passivity symptoms. The research questions were as follows: (1) What is the pattern of performance on measures of body schema, body image and the sense of agency in individuals with schizophrenia compared to controls?; (2) Does the evidence point to a stable trait for schizophrenia (no difference between clinical subgroups), or to quantitative differences depending on the passivity symptom profile? Our hypotheses are that body representation distortions will be present in varying degrees in the clinical population: individuals who are currently symptomatic (with passivity symptoms) will have the most severe abnormalities on all body representations; and those with a past history of symptoms, by virtue of their trait vulnerability, will have greater abnormalities than those with no history of symptoms and healthy controls, but less than those who are currently symptomatic.

3.2 Methods
3.2.1 Participants

The patient sample included individuals with schizophrenia or schizoaffective disorder (53 total, 36 males) recruited from the research database of the WA Family Study of Schizophrenia (Hallmayer et al., 2003; Jablensky, 2004). All patients met both ICD-10 and DSM-IV criteria for a lifetime diagnosis of schizophrenia or schizoaffective disorder, and were community outpatients not currently admitted into a psychiatric hospital and were treated with psychotropic medication. Exclusion criteria included comorbid organic brain disease or substance-use disorder that could account for the psychotic symptoms, or language difficulties.

Healthy controls (48 total, 24 males) were recruited through community advertising. Potential controls were excluded if they had a history of a psychotic disorder, or if any of their first-degree relatives had been diagnosed with schizophrenia, schizophrenia-spectrum, or bipolar affective disorder.

The study protocol was explained to all participants and written informed consent was obtained. The study was approved by the North Metropolitan Mental Health Service Human Research Ethics Committee and conformed to the appropriate regulatory standards.
3.2.2 Clinical evaluation

Clinical evaluation was conducted with the Scales for the Assessment of Positive and Negative Symptoms (SAPS and SANS; Andreasen, 1984a, 1984b). Passivity symptoms were assessed using the Passivity Symptoms Interview (PSI) (Waters, Badcock, Dragovic, & Jablensky, 2009) with selected items from the Schedule for Clinical Assessment in Neuropsychiatry (SCAN, Version 2.1; items: 17.008, 18.005-18.010, 18.012-18.017, see Wing et al., 1990). All symptoms were rated in accordance with stringent definitions and criteria assessed for lifetime history and presence in the last 4 weeks as determined by self-reports and case-note reviews. Patients were rated as having current passivity symptoms (Current group) if they reported two or more such symptoms in the past 4 weeks (n = 20). Patients were rated as ‘Past’ (n = 12) if they had a positive rating of at least two passivity symptoms in the past, but not within the past four weeks or ‘Never’ (n = 21) if they had never experienced these symptoms during any period. Independent classification of patients into groups was conducted by two of the investigators (KG and FW) and rated based on consensus.

3.2.3 Experimental tasks

Hand illusion: Each participant sat in front of a table with a Fujitsu 17” color monitor embedded horizontally in the top, with both hands resting on top of the table. The right hand was hidden behind a removable curtain. An image of this hand was captured by an analogue camera (AVC-561, AVTECH, Taiwan) and transmitted to the monitor via an analogue delay line (DL1B-5379, Ovation Systems Ltd., UK). The real hand and the image of the hand were separated by 15 cm. A photograph of the setup used can be seen in Figure 3.1. There were two delay conditions in the illusion; *synchronous* (< 10 ms video feedback) and *asynchronous* (an additional imposed 500 ms delay). Participants were exposed to each condition once (3 minutes each), with the order of presentation being counter-balanced across participants. A 20 item questionnaire assessing the subjective experience of the illusion was administered after each condition (K. T. Graham, Martin-Iverson, Holmes, et al., 2015); adapted from Longo et al., (2008). Items relating to the component Deafference were not included as the component does not pertain to body representations. Each item was rated on a 7-point Likert scale ranging from -3 (strongly disagree) to +3 (strongly agree). A recent PCA (K. T. Graham, Martin-Iverson, Holmes, et al., 2015) identified that the following
components could be extracted from the questionnaire, assessing body image ("Disembodiment of own hand" and "Embodiment of the ‘Other’ hand"), and the sense of agency ("Agency over the ‘Other’ hand", and “Loss of agency over own hand”) in both synchronous and asynchronous conditions. Table 3.1 shows the 20 items (Embodiment items 1-8, Disembodiment 13-17, Agency 9-10 and Loss of agency 11-12).

Table 3.1. Questionnaire items used during the projected hand illusion

<table>
<thead>
<tr>
<th>It seemed like…</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>… I was looking directly at my own hand, rather than at an image.</td>
<td>Embodiment</td>
</tr>
<tr>
<td>… the image began to resemble my real hand.</td>
<td>Embodiment</td>
</tr>
<tr>
<td>… the image of the hand belonged to me.</td>
<td>Embodiment</td>
</tr>
<tr>
<td>… the image was my hand.</td>
<td>Embodiment</td>
</tr>
<tr>
<td>… the image was part of my body.</td>
<td>Embodiment</td>
</tr>
<tr>
<td>… my hand was in the location where the image was.</td>
<td>Embodiment</td>
</tr>
<tr>
<td>… the image was in the location where my hand was.</td>
<td>Embodiment</td>
</tr>
<tr>
<td>… the touch I felt was caused by the paintbrush touching the image.</td>
<td>Embodiment</td>
</tr>
<tr>
<td>… I could have moved the image of the hand</td>
<td>Agency over the image</td>
</tr>
<tr>
<td>… like I was in control of the image.</td>
<td>Agency over the image</td>
</tr>
<tr>
<td>… I was unable to move my hand.</td>
<td>Loss of agency over own hand</td>
</tr>
<tr>
<td>… I couldn’t have moved my hand if I had wanted.</td>
<td>Loss of agency over own hand</td>
</tr>
<tr>
<td>… I couldn't really tell where my hand was.</td>
<td>Disembodiment</td>
</tr>
<tr>
<td>… my hand had disappeared.</td>
<td>Disembodiment</td>
</tr>
<tr>
<td>… my hand was out of my control.</td>
<td>Disembodiment</td>
</tr>
<tr>
<td>… my hand was moving towards the image.</td>
<td>Disembodiment</td>
</tr>
<tr>
<td>… the image was moving towards my hand.</td>
<td>Disembodiment</td>
</tr>
</tbody>
</table>

**Hand Laterality Task (Parsons, 1987b):** For each trial, a picture of a hand, palm down, was displayed on a computer screen. Participants were instructed to indicate if the hand was a left or right hand by pressing an appropriate key on a keyboard. Each picture was either a left or right hand, and rotated by either 0°, 90° medially, 90°
laterally or 180°. There were six repeats of each hand/rotation combination, for a total
of 48 trials per participant. The stimuli were presented in a random order. Participants
were instructed not to make major movements of their hands or heads while making the
judgments. Four practice trials with feedback were given to each participant before
commencing the main experiment. The experiment was produced using E-Prime 1.2
software (Psychology Software Tools, Pittsburgh, PA). In order to rule out possible
abnormalities in mental rotation, a similar task was conducted in which the letter F was
displayed, instead of a hand. The letter was either oriented normally or mirrored along
the vertical axis. The same number of trials of letter and rotation combinations was used
as the hand laterality task. For both tasks, accuracy and response time were recorded.

Table 3.2. Demographic information of participants

<table>
<thead>
<tr>
<th></th>
<th>Controls (n=48)</th>
<th>Never (n = 21)</th>
<th>Past (n = 12)</th>
<th>Current (n = 20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (M/F) a</td>
<td>24/24</td>
<td>14/7</td>
<td>10/2</td>
<td>12/8</td>
</tr>
<tr>
<td>Age (years) b</td>
<td>46.2 ± 1.68</td>
<td>42.5 ± 1.57</td>
<td>43.6 ± 2.84</td>
<td>44.0 ± 2.06</td>
</tr>
<tr>
<td>Years Education b</td>
<td>13.7 ± 0.35</td>
<td>12.9 ± 0.37</td>
<td>13.0 ± 0.54</td>
<td>13.7±0.57</td>
</tr>
<tr>
<td>WTAR b</td>
<td>104 ± 1.9</td>
<td>100 ± 3.3</td>
<td>95 ± 3.4</td>
<td>96 ± 3.2*</td>
</tr>
<tr>
<td>Trail Making Test A b</td>
<td>31.9 ± 2.82</td>
<td>53.0 ± 7.47</td>
<td>51.2 ± 11.5 **</td>
<td>45.7 ± 8.68</td>
</tr>
<tr>
<td>SAPS Composite b</td>
<td>-</td>
<td>12.0 ± 2.3</td>
<td>19.2 ± 3.5</td>
<td>29.2 ± 3.2</td>
</tr>
<tr>
<td>SANS Composite b</td>
<td>-</td>
<td>21.8 ± 3.6</td>
<td>29.8 ± 4.7</td>
<td>24.7 ± 2.5</td>
</tr>
<tr>
<td>Chlorpromazine</td>
<td>-</td>
<td>677 ± 121</td>
<td>805 ± 140</td>
<td>754 ± 106</td>
</tr>
</tbody>
</table>
equivalents (mg) b

Mean ± SEM of selected covariates. a Fisher’s Exact Test. b One-way ANOVA with
Tukey’s HSD post-hoc comparisons (Bonferroni corrected).
Different from controls: * p<0.05, ** p<0.01, ***p<0.001
Different from Pass. Current: ^ p<0.05, ^^ p<0.01, ^^^p<0.001
Antipsychotic doses converted into chlorpromazine equivalents using the formulae
given in (69-70).

3.2.4 Cognitive tasks

In order to account for possible differences in cognition between the samples
that may affect the main outcome measures, several measures assessing cognition were
employed. The Wechsler Test of Adult Reading (WTAR) (Wechsler, 2001) was
included as a measure of pre-morbid intelligence. Trail Making Test Form A (TMTA)
(Lezak et al., 1995) provided a measure of speed of processing. The Digit Span (DS) provided a measure of attention span (forward span), and working memory (backward span), respectively (Lezak et al., 1995). See table 3.2 for demographic and neuropsychological variables.

3.2.5 Statistical methods

All statistical analyses and figures were completed using the statistical software R (version 3.0.1; R Core Team, 2012), and the packages ‘nlme’ (Pinheiro et al., 2013) and ‘car’ (Fox & Weisberg, 2011). Analyses were performed using linear mixed-effects models with the mean score on the relevant subscale as the dependent variable, delay condition (synchronous or asynchronous) was the within-subjects variable, group (Controls, Current, Past or Never) as the between-subjects variable and participant as the random effects term. Similarly, for the hand laterality task, separate models were created for a) mean accuracy (% incorrect) and b) mean response time (s). For these, group was the between-subjects independent variable and rotation (0°, 90° medial, 90° lateral and 180°) as the within-subjects variable. Performance (% incorrect and response time, respectively) on each rotation for the letter rotation task was included as a

Figure 3.1. Photograph of the projected hand illusion is shown.

covariate in these analyses. Where Analysis of Deviance (ANODEV) on the terms of
the model revealed significant differences, interaction contrasts comparing difference scores on each of the levels of the factor were performed. i.e. [Controls(Synch)-Controls(Asynch)]-[Current(Synch)-Current(Asynch)]. Alpha was set to 0.05.

3.3 Results

3.3.1 Projected hand illusion

Demographic information for participants can be seen in Table 1. Where there were differences between groups, these data were then entered into the projected hand illusion analyses as covariates. However, there were no significant effects of any of the covariates for the PHI data ($p > 0.1$) and so these were removed from the final model.

3.3.1.1 Schizophrenia groups combined

Performance was first examined with a comparison of people with schizophrenia as a group versus healthy controls to determine overall effects of diagnosis while maximizing power to detect an effect. SAPS and SANS scores and chlorpromazine equivalents were included as further covariates in all projected hand illusion analyses but were removed from the final model, as none were significant. People with schizophrenia reported increased feelings of disembodiment ($F(1, 99) = 29.5, p < 0.0001$), and a greater loss of agency over their own hand ($F(1, 99) = 21.3, p < 0.0001$), compared to controls, showing greater deficits identifying the experience of their own body.

There were no main effects of group ($F(1, 99) = 1.83, p = 0.18$) or interaction ($F(1, 1498) = 2.65, p = 0.10$) on the embodiment of the ‘other’ hand component ($F(1, 97) = 3.63, p = 0.06$). Further, there was no significant difference between groups in the sense of agency over the ‘other’ hand ($F(1, 99) = 0.19, p = 0.66$).

3.5.1.2 Group comparisons– Body image (Embodiment of image)

ANODEV revealed no main effects of group on Embodiment ($F(3, 97) = 0.83, p = 0.48$), but there was a significant main effect of delay ($F(1, 1496) = 57.8, p < 0.0001$), with ratings being higher in the synchronous condition. There was a significant interaction between group (controls, Current, Past and Never) and delay condition ($F(3, 1496) = 4.94, p = 0.002$). Interaction contrasts revealed significant differences between Current and each of the other groups: Controls ($p = 0.001$), Never ($p = 0.04$) and Past ($p = 0.0006$). Controls, and patients in the Past and Never groups, all demonstrated embodiment of the hand in the synchronous condition, which was reduced in the
asynchronous condition. By contrast, patients in the Current group showed no difference in performance between the synchronous and the asynchronous conditions, exhibiting embodiment in both conditions (see Figure 3.2a).

Figure 3.2. Questionnaire responses assessing (A) Embodiment, (B) Disembodiment, (C) Agency over the ‘Other’ hand and (D) Loss of agency over own hand, during the projected hand illusion after asynchronous (Asynch) and synchronous (Synch) stimulation in controls, people with schizophrenia with no history of passivity symptoms (Never), people with a past history of passivity symptoms (Past) and people with current experiences of passivity symptoms (Current). Questions were answered on a 7-point Likert scale. Data are mean ± SEM. * p < 0.05, ** p < 0.001, *** p < 0.0001.

3.3.1.3 Group comparisons – Body image (Disembodiment of own hand)

For disembodiment (Figure 3.2b), there was a main effect of group \( F(3, 97) = 13.1, p < 0.0001 \), but not delay condition \( F(1, 892) = 1.25, p = 0.26 \) and the interaction was not significant \( F(3, 892) = 6.78, p = 0.08 \). Disembodiment of own hand was significantly higher in the Past \( p < 0.0001 \), Current \( p < 0.0001 \) and the Never groups \( p = 0.01 \), relative to controls. The Current and Past groups were
marginally significantly different from each other \((p = 0.05)\) but both reported higher disembodiment than the Never group \((\text{Past } p = 0.009, \text{Current } p = 0.04)\).

### 3.3.1.4 Group comparisons– Agency (Agency over the image)

ANODEV revealed no main effect of group \((F(3, 97) = 0.16, p = 0.92)\), but there was a significant main effect of delay condition \((F(1, 292) = 19.2, p < 0.0001)\), with an overall increase in reported agency over the ‘other’ hand in the synchronous compared to asynchronous condition. The interaction between group and delay condition neared, but did not reach, significance \((F(3, 292) = 7.59, p = 0.055)\). However, given the \(p\)-value, it was decided it was reasonable to perform interaction contrasts. Figure 3.2c shows that Controls, Never and Past all demonstrated increased agency over the ‘other’ hand, after synchronous compared to asynchronous stimulation \((\text{treatment contrasts; } p = 0.007, p = 0.002, p = 0.02, \text{respectively})\) while the Current group failed to demonstrate the expected decrease in the asynchronous condition \((p = 0.98)\), and reported similar levels of agency after both synchronous and asynchronous stimulation. However, the only pairwise interaction treatment contrast that was significant was between Current and Never groups \((p = 0.009)\).

### 3.3.1.5 Group comparisons– Agency (Loss of agency of own hand)

For the loss of agency of own hand component, there was a significant main effect of group \((F(3, 97) = 25.0, p < 0.0001)\) and a significant effect of delay condition \((F(1, 293) = 3.97, p = 0.046)\) such that loss of agency ratings were higher in the synchronous condition, but no significant interaction \((F(3, 293) = 0.49, p = 0.69)\). Controls reported significantly less loss of agency over their own hand relative to the Current \((p = 0.004)\), Past \((p < 0.0001)\) and Never groups \((p = 0.003)\), but there were no significant differences between schizophrenia groups \((\text{all } p > 0.1; \text{see Figure 3.2d})\).

### 3.3.2 Hand laterality task

SAPS score, SANS score and chlorpromazine equivalents were initially included as covariates in all hand laterality analyses but none had a significant association so they were excluded from the final model.

#### 3.3.2.1 Schizophrenia groups combined (hand laterality task - response time)

As expected, on response time with the schizophrenia groups and healthy controls, the ANODEV displayed a significant main effect of rotation \((F(3, 700) = 460,\)
with the response time on 0° trials significantly different from 90° Medial (p < 0.0001), 90° Lateral (p < 0.0001) and 180° trials (p < 0.0001). There was a main effect whereby individuals with schizophrenia had longer response times across all rotations (F(1, 99) = 17.7, p < 0.0001), as well as an interaction of group and rotation (F(3, 693) = 12.8, p = 0.005), indicating a further increase in response time on the 90° lateral (p < 0.0001) and 180° rotations (p < 0.0001) compared to controls.

There were significant positive associations between accuracy on the hand laterality task and WTAR scores (F(1, 78) = 15.9, p < 0.0001, slope = 0.26), and accuracy on the letter rotation task (F(1, 560) = 4.91, p < 0.03, slope = 0.06), so these variables were retained as covariates. There was a significant effect of rotation (F(3, 560) = 46.2, p < 0.0001). Contrasts demonstrated that accuracy on 0° trials not different to 90° Medial (p = 0.53) or 90° Lateral (p = 0.08) trials, but significantly different from 180° trials (p < 0.0001). There was no significant main effect of group (schizophrenia group versus Controls) in accuracy (F(1, 78) = 0.14, p = 0.71). There was a significant interaction between group and rotation (F(3, 560) = 9.13, p = 0.03), due to the schizophrenia group being significantly less accurate on the 90° Lateral rotation (p = 0.03).

Figure 3.3. Mean response times (s, columns) and inaccuracy (% lines) of hand laterality judgements at 0°, 90° Medial, 90° Lateral and 180° rotations for Controls, people with no history of passivity symptoms (Never), people with a past history of passivity symptoms (Past) and people with current experiences of passivity symptoms (Current). Data are mean ± SEM. See text for treatment contrasts.

3.3.2.2 Schizophrenia groups combined (hand laterality task - accuracy)

There were significant positive associations between accuracy on the hand laterality task and WTAR scores (F(1, 78) = 15.9, p < 0.0001, slope = 0.26), and accuracy on the letter rotation task (F(1, 560) = 4.91, p < 0.03, slope = 0.06), so these variables were retained as covariates. There was a significant effect of rotation (F(3, 560) = 46.2, p < 0.0001). Contrasts demonstrated that accuracy on 0° trials not different to 90° Medial (p = 0.53) or 90° Lateral (p = 0.08) trials, but significantly different from 180° trials (p < 0.0001). There was no significant main effect of group (schizophrenia group versus Controls) in accuracy (F(1, 78) = 0.14, p = 0.71). There was a significant interaction between group and rotation (F(3, 560) = 9.13, p = 0.03), due to the schizophrenia group being significantly less accurate on the 90° Lateral rotation (p = 0.03).
3.3.2.3 Group comparisons (hand laterality task - response times)

Response time on the letter rotation task covaried significantly with the response time on the hand rotation task ($F(1, 687) = 13.9, p = 0.0002$, slope = 0.10). However, all significant effects remained so with inclusion of the covariate. No other covariates, including chlorpromazine equivalents, were significant. There was a significant main effect of group on response times ($F(3, 97) = 20.6, p < 0.0001$). There was also a significant interaction between group and rotation type ($F(9, 687) = 20.9, p = 0.01$); response times of Current and Past were significantly longer than controls at 90° lateral ($p = 0.03$ and $p = 0.03$) and 180° rotations ($p = 0.009$ and $p = 0.005$), and Never had significantly greater response times compared to Controls at all rotations (0°, $p = 0.01$; 90° medial, $p = 0.002$; 90° lateral, $p < 0.0001$; 180°, $p < 0.0001$) (Figure 3.3).

3.3.2.4 Group comparisons (hand laterality task - accuracy)

There was a significant interaction between group and rotation ($F(9, 554) = 27.9, p = 0.001$), as well as a significant main effect of rotation ($F(3, 554) = 47.4, p < 0.0001$). To investigate the cause of the interaction between group and rotation type, interaction treatment contrasts were performed. There were no significant group differences at 90° medial rotation (all $p > 0.3$). At 90° lateral rotations, the Current and Past (but not Never) were significantly less accurate than controls ($p = 0.006$ and 0.007 respectively). At 180° rotations, only Past were significantly less accurate than controls at 180° rotations ($p = 0.0007$). There was no main effect of group ($F(3, 76) = 0.94, p = 0.20$) on accuracy. In regards to the covariates, higher accuracy on the letter rotation task was associated with higher accuracy of hand laterality judgments ($F(1, 554) = 4.61, p = 0.01$, slope = 0.06), and a higher WTAR score was associated with higher accuracy ($F(1, 76) = 14.9, p = 0.002$, slope = 0.26). All significant effects remained after inclusion of the covariates.

3.4 Discussion

The main aim of the current study was to assess the integrity of body representations in individuals with schizophrenia compared to controls, and the pattern of performance with regards to the presence of passivity symptoms, on a body illusion and a hand laterality task.
3.4.1 What is the pattern of performance in individuals with schizophrenia compared to controls?

Individuals with schizophrenia showed abnormal performance on both the hand illusion and hand laterality tasks. During the hand illusion, individuals with schizophrenia, as a group, showed increased disembodiment of their own hand, as well as a decreased sense of agency over their own hand, relative to controls.

The hand illusion, with its subjective reports, provides a particularly convenient method to examine components of body representations, and self and non-self dimensions, in one experimental set-up. The current study showed a dissociation in performance by people with schizophrenia between self-embodiment/agency and other-embodiment/agency. Specifically, there was no significant difference between the schizophrenia and controls groups on embodiment and sense of agency over the ‘other’ hand, although the clinical group was particularly impaired on trials requiring the processing of their own (self) body. This perhaps suggests that the representation of other/external people is relatively preserved in schizophrenia, but that the representation of their own body is impaired. In other words, these individuals may be particularly susceptible to disruptions in self-processes, producing a sense of disconnectedness from their own body, but that the embodiment and sense of agency over external objects/bodies is unaffected*. In a speculative tone, the imbalance between self- and non-self representations may give rise to distortions regarding the inference of other people’s intention, perhaps triggering or increasing the vulnerability to delusions.

Disordered self-agency is a common finding in experimental tasks testing the forward model and cognitive self-monitoring models (Blakemore, Smith, et al., 2000; Cahill, Silbersweig, & Frith, 1996; Daprati et al., 1997; Franck et al., 2001; Synofzik et al., 2010). However, few studies have demonstrated disembodiment in schizophrenia. While patients frequently complain of diminished representations of the bodily-self (Parnas, 2000; Schneider, 1946), depersonalization and feeling of disembodiment (Röhricht & Priebe, 1996, 2002), and self-referential processing difficulties (Blakemore, Smith, et al., 2000; Röhricht & Priebe, 1996), such subjective reports are rarely assessed in experimental conditions. Altogether, the current findings, using a hand illusion, provide support for anomalies in self-agency and self-ownership, in this group.

Performance on the hand laterality task provided evidence of additional changes in body schema. On this task, individuals with schizophrenia took significantly longer to respond than controls. In addition, this clinical group had significantly lower accuracy on 90° lateral trials. These are the most difficult trials, even in healthy groups,
and performance is typically less accurate and slower than on the other trials (Parsons, 1987b). In individuals with schizophrenia, this pattern of performance on error and latency measures could not be explained simply in terms of impaired visuospatial abilities or generally slower responses, since controlling for performance on the letter rotation task, with the same rotation conditions, did not change the results. Given that the hand laterality task is under the same biophysical constraints as performed actions, the current results point to specific difficulties in the processes involving the synchronization of proprioceptive and tactile inputs into a representation of the body in space in schizophrenia. These findings on the hand laterality task underscore those of de Vignemont et al. (n = 13) (2006). In contrast to the current study, however, they showed an increase in errors on all rotations in their schizophrenia group relative to controls. Their task was similar to ours, so it is likely that differences in patient characteristics or in statistical power contributed to this small difference in performance.

Together, the current findings point to deficits in sense of agency, body image and body schema in schizophrenia. Performance on these tasks was not related to chlorpromazine equivalents so antipsychotics dosages are an unlikely contributor to performance. Similarly, performance on the task was not correlated with other clinical or cognitive performance score. We believe it is the first report of deficits in multiple body representations in schizophrenia.

3.4.2 Does the evidence point to a stable trait for schizophrenia (no difference between clinical subgroups), or to quantitative differences depending on the passivity symptom profile?

If abnormal body representations represent a stable trait for schizophrenia in toto, then no significant differences between Current (current presence of passivity), Past (past history of passivity) and Never (no history of passivity) would be expected, although they would still perform differently from controls. Only partial evidence was found for this suggestion. Specifically, evidence for such a ‘stable trait’ was only observed in the domain of agency, where a reduced sense of agency over one’s own hand was a common feature of all three patient groups.

By contrast, performance on the other variables supported our initial hypothesis that there should be quantitative differences between people with passivity symptoms (‘Current’) compared to individuals with a history of these symptoms (‘Past’), and individuals with no lifetime history of passivity (‘Never’). Performance on tasks assessing body image suggested quantitative differences depending on the passivity
symptom profile of the clinical group. Individuals with passivity symptoms (both current and past) had significantly greater changes in body image, as indicated by their higher rating of items relating to disembodiment, compared to the group with no history of these symptoms, who in turn reported more disembodiment compared to healthy controls.

In accordance with the above, on the hand laterality task, the Current and Past groups demonstrated reduced accuracy on judgments of the 90° lateral, and 180° (Past only) rotations. This finding is in line with demonstrations of impaired performance on a task of motor imagery in people with motor passivity symptoms (Maruff et al., 2003). While this points to problems in body schema, it is important to note that actions and proprioception remain largely unimpaired in this group (Delevoye-Turrell et al., 2002; Synofzik et al., 2008). This suggests that only some subcomponents of body schema are impaired, either in the access pathways to this information, or in the integration with other body representations (Maruff et al., 2003).

In sum, the evidence points to both general (trait) deficits in all individuals with schizophrenia (the sense of agency), and quantitative (specific) differences depending on the passivity symptom profile (body image, and body schema). Questions remain however, regarding the processes that separate individuals with current passivity symptoms from those with a history of these symptoms. Both groups show deficits in sense of agency, body image and body schema, so these processes are not sufficient alone for passivity symptoms. What determines whether patients experience these symptoms? A clue lies in the examination of performance on the hand illusion, specifically on the asynchronous condition.

3.4.3 Decreased sensitivity to timing delays associated with passivity symptoms

On all measures of the hand illusion involving timing delays, individuals in the Current passivity group distinguished themselves from the other groups. Most remarkably, they failed to demonstrate the normal reduction in the body illusion typically seen with a 500 ms delay in visual feedback (asynchronous condition). This performance was specific to those in the Current group, as the other clinical groups (including the Past group) showed the expected illusory decrease on the asynchronous condition. In other words, individuals with passivity symptoms continued to experience illusions of embodiment and sense of agency over the ‘other’ hand, when the other groups didn’t. This suggests that the temporal window that provides links between self and external stimuli is significantly, and abnormally, elongated in people with passivity
symptoms. Alternatively, it is possible that the Current group uses temporal cues during multisensory integration to a lesser extent than the other groups.

The functional significance of this finding cannot be understated, given that internal timing precision is critical for a range of processes including sensory-motor awareness and self-recognition (Blakemore, Smith, et al., 2000; Haggard et al., 2003; Waters, 2013). Precise timing is needed for the synchronization of motor, cognitive and sensory signals. It is also needed to shape sensory awareness, and in the formation of causal mental associations. Specifically, voluntary actions which are followed by a sensory event are perceived as shifted closer together in time than they actually are, a psychological phenomenon termed intentional binding (Haggard et al., 2002) which contributes towards the sense of self-agency. Abnormal internal timing mechanisms in people with passivity symptom therefore have much explanatory power for their disordered self-attribution system. Other evidence is provided by studies showing time perception impairments in individuals with schizophrenia (Elvevag et al., 2003; Franck et al., 2005). Passivity symptoms studies also show dysfunctions in cognitive and motor timing. Specifically, these individuals perceive external events to be closer in time together than they are, (Blakemore, Smith, et al., 2000; S. A. Spence, 1996; Waters & Jablensky, 2009) which may impact on the integrity of self- and non-self attribution processes.

The current hand illusion findings are particularly pertinent, because they show that individual with passivity symptoms experience an illusory sensation of ownership and agency over an image that is spatially and temporally disjointed from the sensorimotor processes linked to their real hand. It is therefore not surprising that these individuals do not feel in control of their movements, and that they experience confusion regarding the origins of their actions and intentions. Such fragmented phenomena would lead to substantial confusion for internally-generated events. If a larger window of integration was indeed closely associated with passivity symptoms, it would be expected to have impact on other behaviors and also other non-body related illusions such as the ventriloquist illusion.

A possible mechanism might occur via dopaminergic pathways. Using an amphetamine challenge in healthy volunteers as a model of psychoses-related responses in the rubber hand illusion, our group (Albrecht et al., 2011) found that amphetamine appeared to increase the temporal envelope of associability of the rubber hand visual cues to the feel of the stroking (i.e., had a selective effect of increasing the illusion in the asynchronous condition) in a profile of performance which was similar to the
pattern of performance in the Current group. Together with their functional role of assigning salience to external stimuli (Voss et al., 2010), dopaminergic pathways may well contribute to confusion, and misattribution, of agency via changes in the normal temporal window for associability such that external cues become a possible source of body input.

3.4.4 Strengths and limitations of the current study

It should be noted here that the hand illusion offers significant advantage over other paradigms assessing sense of agency in schizophrenia (Synofzik et al., 2010; Voss et al., 2010). Notably, subjective reports of online and prospective actions (e.g. “I am able to move it”) in the hand illusion are superior to tasks assessing actions retrospectively (“I moved it”), therefore overcoming criticisms about the involvement of other cognitive processes (Voss et al., 2010) which render such retrospective predictions unreliable (Synofzik et al., 2010) (also see (Moore, Lagnado, Deal, & Haggard, 2009; Synofzik et al., 2008)). Such differentiation between prospective and retrospective assessments is thought to be significant when assessing agency reliably (Voss et al., 2010). That the items of the questionnaire of the current study assessed prospective agency, possibly explains why there was no significant difference between the schizophrenia groups on the loss of agency over own hand questions; it would appear that the changes in agency are limited to retrospective agency in passivity symptoms. Confirmation of this finding could not be carried out as the current study did not assess retrospective agency.

A further limitation of the current study is Current group had a significantly higher level of positive symptoms as assessed on the SAPS. It may therefore be that overall illness severity contributed to the current results, rather than the presence of passivity symptoms. However, several lines of evidence argue against this proposal: (i) there were no significant associations of SAPS scores with any of the dependent variables; (ii) SANS scores did not differ between groups; (iii) chlorpromazine equivalents did not differ between groups; and (iv) the groups did not differ from each other on cognitive performance.

3.4.5 Conclusion

To conclude, the current study demonstrated both stable traits in schizophrenia (sense of agency), and some quantitative differences depending on passivity symptom profile (body image and body schema). In addition, the presence of passivity symptoms
was linked to an enduring experience of body illusion that was resistant to both spatial separation and temporal delay. Our proposal is that passivity symptoms are linked to deficits in body representations encompassing body image and body schema, changes in the sense of agency, alongside internal timing problems that contribute to excessive associability with external sensory stimuli, producing the sensation that one’s actions are controlled by an external agent.

**Contributors**

Kyran T. Graham conducted all participant testing, statistical analyses and wrote the first draft of the manuscript. Flavie Waters and Assen Jableksny contributed to the conception of the project and to the design of the study. Kyran T. Graham, Mathew Martin-Iverson and Nicholas Holmes provided input into the experimental procedures and testing. All authors contributed to manuscript drafts.

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Preface to Chapter 4

It was demonstrated in chapter 3 that people with passivity symptoms (current or past history of symptoms) have more pronounced alterations in body schema, body image and body agency, as assessed with the projected hand illusion, compared to people with schizophrenia with no history of passivity symptoms and healthy controls.

The main aim of chapter 4 was to assess a different body representation, body structural description, in people with schizophrenia. To achieve this, two tasks were utilised that have been used previously to assess body structural description: the in-between task (IBT) and the "matching body part by location" task (MBPBL). These two tasks were chosen to assess body structural description on a fine level of acuity (IBT) and at the level of whole body parts (MBPBL). The main variable of interest was accuracy on both tasks. As with chapter three, the people with schizophrenia were divided into groups based on experience of passivity symptoms.

The fourth chapter also aimed to provide further evidence of body image changes in schizophrenia and passivity symptoms, outside of experimental manipulations. The PHI involves manipulation of the experience of the bodily self outside of normal conditions and so does not represent “usual” experience. To assess body image alterations in situ, a body distortion questionnaire (BDQ) was administered to participants, with subscales assessing experiences of depersonalisation, loss of the physical boundaries of the body, unusually large body parts and unusually small body parts.

As with chapter three, it was hypothesised that the greatest alterations of body structural description (lower % correct on the IBT and MBPBL) and body image (a higher response to items of the subscales of the BDQ) would be observed in people with a current experience of passivity symptoms, followed by people with a past history of passivity symptoms, people with schizophrenia with no history of passivity symptoms and finally healthy controls.
Chapter 4 - Alterations of body structural description and body image in people with schizophrenia, with and without passivity symptoms

Abstract

Individuals with schizophrenia, and particularly those with passivity symptoms, experience reduced control over their actions and thoughts and feel they are controlled by an external agent. Recent evidence has elucidated the important role that body schema and body image play in the aetiology of passivity symptoms, yet a third body representation - body structural description - has not yet been examined. Additionally, body image has rarely been examined outside of tasks of body illusions (e.g. rubber hand experiments) and external validation is required. In the current study, body structural description was assessed by examining whether participants could determine the relationship between fingers (in-between task) and of body parts relative to each other (matching body parts by location task), and body image with a questionnaire examining body distortion experiences (boundary loss, depersonalisation and body size distortions). Clinically stable individuals with schizophrenia (20 with current, 12 with past and 21 with no history of passivity symptoms) and 48 healthy controls participated in the study. Compared to controls, people with schizophrenia made more errors on the in-between task, but not on the matching body parts by location task, with no differences in performance on either task between schizophrenia groups. The absence of brain region/s implicated in both passivity symptoms and body structural description is likely why body structural description alterations were not unique to people with passivity symptoms. Individuals with current passivity symptoms reported greater body distortions on all subscales relative to all the other clinical samples, except for experiences of boundary loss which were common to both passivity symptom groups. Altogether, the results extend our current knowledge of the body representation profile in this clinical group, with alterations of i) body image that are specific to passivity symptoms and ii) body structural description that are a trait feature of individuals with schizophrenia.
4.1 Introduction

In the cognitive neuroscience fields, the ‘sense of self’ refers to a complex introspective representation that is derived from the integration of cognitive, sensory and motor signals, and which forms an intermittently interrupted “stream of consciousness”, making a life-long single narrative (Albrecht et al., 2012). A longstanding framework regards schizophrenia as a disorder defined by a fundamental disturbance in the sense of self. For example, Kraepelin (1913), Bleuler (1911) and Schneider (1946) all invoked impairments in the sense of self in their early descriptions of this psychiatric condition. Recently, there has been a revival of such theoretical frameworks (Parnas, 2000; Sass & Parnas, 2003). Passivity symptoms (experience of alien control) are a particularly pronounced form of self-disturbance (Jansson, 2015) and refer to a perceptual change in how the sense of self is experienced, such that individuals do not feel in control of their movements and believe that their actions and intentions are controlled by an external agent.

For a long time, the predominant model regarding the aetiology of passivity symptoms proposed that a core deficit lies in the sense of agency (the sense that one is the initiator of an action). According to this framework, such agency deficits are the consequence of the breakdown of the forward model which is a neurophysiological mechanism responsible for predicting the sensory consequences of intentional movements (Feinberg, 1978; Frith, 1992, 2005; Miall & Wolpert, 1996). However, it has been repeatedly shown that this model is unable to explain the core pathological or phenomenological features of these symptoms (see Hirjak et al., 2013; Parnas et al., 2003) and is neither adequate nor sufficient as a theoretical model (Gallagher, 2004; Synofzik et al., 2006; Waters & Badcock, 2010).

A recent model proposes that passivity symptoms may in fact reflect broad deficits in body representations (Waters & Badcock, 2010). Body representations are internal representations of the self derived from multiple cognitive systems, sensory input and efferent motor commands which inform the way that sense of self is experienced. There are at least four body representations; body schema, body agency, body image and body structural description. The current study investigates the latter two. Body image refers to a top-down cognitive representation that integrates the conscious perceptual experiences of one’s body, contributes to one’s beliefs and attitudes about one’s body and provides semantic information relating to the names and functions of body parts (Coslett et al., 2002; Gallagher, 2005; Paillard, 1999). Body structural description provides a stored mental representation of the spatial relationship...
between body parts and the junctions between them, derived from visual input (Corradi-Dell'Acqua et al., 2008; Coslett et al., 2002; Schwoebel & Coslett, 2005; Sirigu et al., 1991). Studies of focal brain lesions (Arzy, Overney, et al., 2006; Sirigu et al., 1991) and functional brain imaging studies (Corradi-Dell'Acqua et al., 2009; Ehrsson et al., 2005; Rusconi et al., 2014; Wolpert et al., 1998) provide support for the validity of these constructs.

There is strong evidence for body image alterations in schizophrenia, as shown using a ‘body distortion’ questionnaire (Priebe & Röhricht, 2001; Röhricht & Priebe, 1996, 2002) and the rubber hand illusion (Peled et al., 2003; Peled et al., 2000; Thakkar et al., 2011), although the link with symptom profile was not examined in these studies. More recently, we found body image changes to be an enduring and trait-like characteristic of passivity symptoms, given that individuals with both current and a past history of passivity symptoms reported elevated sensations of disembodiment elicited by the projected hand illusion (K. T. Graham, Martin-Iverson, Holmes, Jablensky, & Waters, 2014). However, these changes were demonstrated using an illusion that does not represent “everyday” bodily experience. Further evidence from another task would strengthen the case for such body image changes in passivity symptoms. By contrast to the emerging literature on body image, to our best knowledge, no study has investigated the integrity of body structural description in schizophrenia, so that an examination of performance in undifferentiated sample, and in subgroups classed into symptom profile is warranted.

Finally, the specificity of changes in body representations to passivity symptoms is still not clear. According to one framework (Jansson, 2015; Parnas, 2015), there should be quantitative differences in body representations between subgroups of individuals with schizophrenia, with the more severe deficits in those currently symptomatic with passivity symptoms, the least deficits in those without any history of these symptoms, and individuals with a past experience of passivity symptoms performing intermediately. For the current study, it was hypothesised that the severity of changes in body structural description and body image would be dependent upon the passivity symptom profile of the clinical sample.

Overall, the aims of the study were to assess the performance on measures of body structural description and body image in individuals with schizophrenia compared to controls, and to determine if there are quantitative differences in body representations depending on the passivity symptom profile. We hypothesised that body representation alterations (higher positive responses on the subscales of the body distortion
questionnaire and more errors on the in-between and matching body parts by location tasks) would be strongest or more common in individuals who were currently symptomatic with passivity symptoms, followed by those with a past history of symptoms, those with no history of passivity symptoms and then healthy controls.

4.2 Methods

4.2.1 Participants

The clinical sample included individuals (53 total, 36 males) recruited from the research database of the Western Australian Family Study of Schizophrenia (Hallmayer et al., 2003; Jablensky, 2004). All people with schizophrenia met both International Classification of Diseases (ICD-10) and Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) criteria for a lifetime diagnosis of schizophrenia or schizophrenia-spectrum disorder, and were community outpatients stabilized on medication. Exclusionary criteria included language difficulties, comorbid organic brain disease or substance-use disorder that could account for the psychotic symptoms. Community individuals (24 males and 24 females) took part in the study as controls (see Table 4.1 for demographics). Participants were recruited through community advertising. Exclusion criteria for all control participants included organic brain disease, substance-use disorder or a diagnosis of a schizophrenia-spectrum disorder or psychosis. Participants were screened for all major psychiatric disorders using the Mini-International Neuropsychiatric Interview (MINI).

The study protocol was explained to all participants and written consent was obtained. Participants were reimbursed for their time. All study protocols conformed to the guidelines of, and were approved by, the North Metropolitan Mental Health Service Human Research Ethics Committee.

4.2.2 Clinical evaluation

Clinical evaluation was conducted with the Scales for the Assessment of Positive and Negative Symptoms (SAPS and SANS; Andreasen, 1984a, 1984b). Passivity symptoms were assessed using the Passivity Symptoms Interview (PSI; Waters et al., 2009) with selected items from the Schedule for Clinical Assessment in Neuropsychiatry (SCAN, Version 2.1; items: 17.008, 18.005-18.010, 18.012-18.017, see Wing et al., 1990). All symptoms were rated in accordance with stringent definitions and criteria and were assessed for lifetime history and presence in the last 4 weeks as determined by self-reports and case note reviews.
Table 4.1. Demographic information of participants

<table>
<thead>
<tr>
<th></th>
<th>Controls (n=48)</th>
<th>Never (n = 21)</th>
<th>Past (n = 12)</th>
<th>Current (n = 20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (M/F)</td>
<td>24/24</td>
<td>14/7</td>
<td>10/2</td>
<td>12/8</td>
</tr>
<tr>
<td>Age (years)</td>
<td>46.0 ± 1.68</td>
<td>42.5 ± 1.57</td>
<td>43.6 ± 2.84</td>
<td>44.0 ± 2.06</td>
</tr>
<tr>
<td>Education (years)</td>
<td>13.7 ± 0.35</td>
<td>12.9 ± 0.37</td>
<td>13.0 ± 0.54</td>
<td>13.7±0.57</td>
</tr>
<tr>
<td>WTAR</td>
<td>104 ± 1.90</td>
<td>100 ± 3.35</td>
<td>95.2 ± 3.36</td>
<td>95.6 ± 3.15 *</td>
</tr>
<tr>
<td>Trail Making Test A</td>
<td>31.9 ± 2.82</td>
<td>53.0 ± 7.47</td>
<td>51.2 ± 11.5</td>
<td>45.7 ± 8.68</td>
</tr>
<tr>
<td>SAPS Composite</td>
<td>-</td>
<td>12.0 ± 2.27</td>
<td>19.2 ± 3.49</td>
<td>29.2 ± 3.19</td>
</tr>
<tr>
<td>SANS Composite</td>
<td>-</td>
<td>21.8 ± 3.58</td>
<td>29.8 ± 4.66</td>
<td>24.7 ± 2.50</td>
</tr>
<tr>
<td>Chlorpromazine equivalents (mg)</td>
<td>-</td>
<td>677 ± 121</td>
<td>805 ± 140</td>
<td>754 ± 106</td>
</tr>
</tbody>
</table>

Mean ± SEM of selected covariates.  

\(^a\) Fisher’s Exact Test. \(^b\) One-way ANOVA with Tukey’s HSD post-hoc comparisons (Bonferroni corrected).

Different from controls: * p < 0.05, ** p < 0.01, ***p < 0.001

Different from Current: ^^^ p < 0.001

Antipsychotic doses converted into chlorpromazine equivalents using the formulae given in (Bazire, 2009; D. Taylor, Paton, & Kapur, 2009; Woods, 2003).

Patients were rated as having current passivity symptoms (Current group) if they reported at least two such symptoms in the past 4 weeks (n = 20). Patients were rated as ‘Past’ (n = 12) if they had a positive rating of at least two passivity symptoms in the past, but not within the past four weeks or ‘Never’ (n = 21) if they had never experienced these symptoms during any period. Independent classification of patients into groups was conducted by two of the investigators (KG and FW) and rated based on consensus. One control and two patients could not complete the in-between task, two controls and three patients were unable to complete the matching body parts by location task.
4.2.3 Materials & Procedures

A questionnaire assessing age, sex, years of education and self-reported medical problems was administered to all participants.

The Digit Span (DS) provided a measure of attention span (forward span), and working memory (backward span), respectively (Lezak et al., 1995). The Wechsler Test of Adult Reading (WTAR; Wechsler, 2001) was included to provide a measure of premorbid intelligence. Trail Making Test Form A (Lezak et al., 1995) provided a measure of speed of processing.

In-between task (Kinsbourne & Warrington, 1962): The participants sat with their eyes closed and with their hands resting on their knees. On each trial, two fingers on the participant’s dominant hand were stimulated. The stimulation consisted of the experimenter manually firmly pressing the finger, just above the fingernail, for approximately one second. Care was taken to ensure the touch was in the correct location, at the same pressure and for the same length of time. Participants made unspeeded verbal responses as to how many fingers they felt were between the fingers that were touched, and their response was recorded by the experimenter. The order of the trials was determined in a pseudo-random manner before testing began. There are ten possible combinations of fingers that could be stimulated and each combination was presented three times for a total of 30 trials. This task has been used in the neurological literature to assess the effects of cortical lesions on body structural description (Kinsbourne & Warrington, 1962; Ogden, 1985; Tucha, Steup, Smely, & Lange, 1997) and has been used to assess body structural description in healthy controls (Rusconi et al., 2009; Rusconi et al., 2014; Schütz-Bosbach, Musil, & Haggard, 2009).

Matching body parts by location task (Schwoebel & Coslett, 2005): The experiment was delivered on a computer with E-Prime 1.2 software (Psychology Software Tools, Pittsburgh, PA). On each trial, four images of body parts were presented: three pictures on the left hand side of the screen and one on the right hand side. Participants were instructed to determine which of the three body parts on the left was closest to the target body part on the right, imagining going over the surface of their body and using their own body like a map. The pictures remained on screen as long as the participant needed, and then disappeared after their response was entered on a keyboard. There were 13 body parts used (ankle, stomach, chest, chin, ear, elbow, fingers, knee, neck, nose, shoulder, toes and wrist), with 40 randomly selected unique combinations (trials) of the body parts, presented in a single block. The response was recorded by the computer and accuracy determined. Participants were given two
practice trials, and the experimenter ensured that the instructions were fully understood before initiating the task.

Body distortion questionnaire (Fisher, 1970; Röhricht & Priebe, 1996). The questionnaire comprised selected subscales and a total of 48 items. Individuals were asked to report whether they had any of the following experiences in the past four weeks: ‘boundary loss’ (subjective loss of the physical boundaries of the body; 10 items), ‘depersonalisation’ (reduction in the intensity of the experience of the self; 10 items) ‘large’ (body parts feeling as if they are larger than normal; 14 items) and ‘small’ (body parts feeling if they are smaller than normal; 14 items). Participants answered on a 7-point Likert scale ranging from -3 (strongly disagree), through 0 (neutral), to +3 (strongly agree).

4.2.4 Statistical methods

All statistical analyses and figures were completed using the statistical software R (version 2.15.2; R Core Team, 2012), and the packages ‘nlme’ (Pinheiro et al., 2013) and ‘car’ (Fox & Weisberg, 2011). Analyses were performed using linear mixed-effects models with % correct as the dependent variable for the in-between and matching body parts by location tasks, group as the fixed effect with random participant effects for the random error term. Similarly, for the body distortion questionnaire mean score on the relevant subscale was the dependent variable, group (Controls, Current, Past or Never) was the fixed effect, with random participant effects for the random error term. Where differences on the demographic and cognitive variables were found, these were entered as covariates in the model. However, none of the covariates reached significance and so were subsequently removed from the model. Where analysis of deviance (ANODEV) on the terms of the model revealed significant differences, linear treatment contrasts were performed; comparisons were corrected using the Holm-Bonferroni method. Alpha was set to 0.05.

4.3 Results

4.3.1 In-between task
On % correct on the in-between task, the ANODEV revealed a significant main effect of group \( (F(1, 96) = 5.32, p = 0.02) \), with people with schizophrenia making more errors than controls on the in-between task. A significant main effect of group was also found in the ANODEV that included the controls and patients divided into groups based on their history of passivity symptoms \( (F(3, 94) = 8.69, p = 0.03) \). The treatment contrast between Controls and the Never group was significant \( (p = 0.007) \) but no other contrasts were significant \( (p > 0.05) \). The pattern of performance can be seen in Figure 4.1 (A); people who had no history of passivity symptoms made the most mistakes on the in-between task, with Current and Past groups performing at a level intermediate between Controls and Never.

**Figure 4.1.** Percentage accuracy on tasks assessing body structural description in passivity symptoms. The two tasks were the (A) in-between and (B) matching body parts by location tasks. Participants were healthy controls (Controls), people with schizophrenia with no history of passivity symptoms (Never), people with schizophrenia with a history of passivity symptoms but not within the previous four weeks (Past), and people with schizophrenia with a current experience of passivity symptoms within the previous four weeks (Current). Data shown are mean ± SEM. **\( p < 0.01 \).**

4.3.2 Matching body parts by location

In contrast to the in-between task, there was no significant main effect of group on the error rate of the matching body parts by location task \( (F(1, 94) = 2.00, p = 0.16) \) when the groups of people with schizophrenia were combined. The analysis of the error rates of the matching body parts by location task with patients divided by their history
of passivity symptoms also found no significant main effect of group \((F(3, 92) = 3.4, p = 0.32)\). The means of the error rates of each group can be seen in Figure 4.1 (B).

4.3.3 Body distortion questionnaire

The cohort vs control comparison showed a significant effect of group on all subscales ('boundary loss', \(F(1, 99) = 33.1, p < 0.0001\); ‘depersonalisation’, \(F(1, 99) = 25.1, p < 0.0001\); ‘large’ \(F(1, 99) = 26.5, p < 0.0001\) and ‘small’, \(F(1, 99) = 23.1, p < 0.0001\), with people with schizophrenia responding with elevated scores on items describing loss of boundaries, experiences of depersonalisation, and perception of changed size of body parts (both smaller and larger) in comparison to controls. The next set of results now examines the specificity or severity of these changes to the symptom profile.

4.3.3.1 Boundary loss with passivity symptom profile

From the ANODEV, there was a significant main effect of group \((F(3, 97) = 48.8, p < 0.0001)\). One contrast was not significant: Never and Past groups reported similar levels of experiences of loss of boundaries \((p = 0.45)\). The difference in ratings between Current and Past on the ‘boundary loss’ subscale neared, but did not reach, significance \((p = 0.06)\). The average response of Controls and Current \((p < 0.0001)\), Controls and Past \((p = 0.009)\), Controls and Never \((p = 0.02)\) and Current and Never \((p = 0.004)\) were all significantly different. As can be seen in Figure 4.2 (A), the Current group reported significantly greater ‘boundary loss’ experiences, the Past group experienced boundary loss at an intermediate level between Current and Never, with Never reporting the least experiences of the three schizophrenia groups.

4.3.3.2 Depersonalisation

From the ANODEV, there was a significant main effect of group \((F(3, 97) = 37.7, p < 0.0001)\). Only two treatment contrasts were not significant: Never and Past groups reported similar levels of experiences of depersonalisation \((p = 0.85)\), as did Controls and Past \((p = 0.09)\).
Figure 4.2. Body image in passivity symptoms as assessed by the body distortion questionnaire. Participants completed a questionnaire detailing experience of the following subscales in the four weeks preceding their testing appointment: (A) Boundary; (B) Depersonalisation; (C) Large; and (D) Small. Questions were rated on a 7-point Likert scale ranging from -3 (completely disagree), through 0 (neutral) to +3 (completely agree). Participants were healthy controls (Controls), people with schizophrenia with no history of passivity symptoms (Never), people with schizophrenia with a history of passivity symptoms but not within the previous four weeks (Past), and people with schizophrenia with a current experience of passivity symptoms within the previous four weeks (Current). Data shown are mean ± SEM. * $p < 0.05$, ** $p < 0.01$, **** $p < 0.0001$
The questionnaire scores of Controls and Current ($p < 0.0001$), Controls and Never ($p = 0.03$), Current and Never ($p = 0.03$) and Current and Past ($p = 0.03$) were all significantly different. As can be seen in Figure 4.2 (B), the Current group reported significantly greater depersonalisation experiences and the Never and Current groups reported an intermediate level of experiences of depersonalisation between the Current and Controls groups.

4.3.3.3 Large

There was again a significant main effect of group on the responses to the ‘large’ subscale ($F(3, 97) = 32.3, p < 0.0001$). On this subscale, Controls rated items pertaining to the ‘large’ subscale lower than Never ($p = 0.02$), Past ($p = 0.048$) and Current ($p < 0.0001$). The three groups of people with schizophrenia did not significantly differ from each other (Current and Past $p = 0.20$, Current and Never $p = 0.13$, Never and Past $p =0.93$). This can be seen in Figure 4.2 (C).

4.3.3.4 Small

Finally, on the ‘small’ subscale, there was a significant main effect of group ($F(3, 97) = 26.6, p < 0.0001$). Controls reported lower scores on the ‘small’ subscale in comparison to Current ($p < 0.0001$) and Never ($p = 0.01$). All other treatment contrasts were not significant ($p > 0.05$). As can be seen in Figure 4.2 (D), the Current group rated items relating to the sensation of body parts being smaller than normal the highest, with Past and Never intermediate between Current and Controls.

4.3.3.5 Ratings of Current passivity symptoms group

Given that the Current group consistently rated the questionnaire items higher than the other three groups, there remains the possibility of a bias in response by the Current group, rather than distorted bodily experiences. To examine this possibility, an ANODEV was conducted on the questionnaire data of the Current group alone, with questionnaire ratings as the dependent variable and subscale as the within-subjects independent variable. This demonstrated a significant main effect of subscale ($F(3, 57) = 11.3, p = 0.015$). Treatment contrasts indicated that items from the ‘small’ subscale were rated lower than items from the ‘boundary loss’ ($p = 0.002$) and ‘large’ ($p = 0.03$) subscales and neared, but did not reach, significance from the ‘depersonalisation’ subscale ($p = 0.06$). This differential pattern of response to the subscales means that the
Current group were not simply rating every item highly and so a response bias is unlikely.

4.4 Discussion

The aim of the current study was to investigate body representations (body structural description and body image) in a sample of people with schizophrenia who were classified according to their lifetime and present history of passivity symptoms. The findings will now be discussed in turn.

4.4.1 Body structural description in schizophrenia

The study showed contrasting findings on the matching body parts by location task and the in-between task. The schizophrenia groups performed no different from controls on the first task, but made more errors on the in-between task. There may be several reasons for such an apparent disparity.

First, there is the possibility that the matching body parts by location task was not sensitive enough to detect alterations in body structural description. However, the task is sensitive to cortical lesions in neurological patients (see below), suggesting this is an unlikely explanation.

Second, it is also possible that the availability of an online visual representation of the body during performance on the tasks assessing body structural description impacted the results. During the matching body parts by location task, the presence of online visual information could conceivably compensate for alterations in the stored visuospatial representation of the body. However, this is unlikely as the online information would still have to be mapped onto the body structural description and alterations in this representation would presumably impair this process.

Third, the possibility exists that people with schizophrenia may have selective alterations within the body structural description. Indeed, if people with schizophrenia had complete disruptions of body structural description, they would display symptoms of autotopagnosia; people with this disorder perform significantly worse on the matching body parts by location task compared to healthy controls (Schwoebel & Coslett, 2005). Autotopagnosia is caused by lesions of the left inferior parietal cortex or left intraparietal sulcus and is characterised by the inability to describe the relationship between body parts or to locate body parts on the body in relation to other body parts (Buxbaum & Coslett, 2001; Denes et al., 2000; Guariglia et al., 2002; Schwoebel et al., 2001; Sirigu et al., 1991). Taking this into consideration, it is possible that there are
separate structural representation for fingers and the body and it is the former that is altered in people with schizophrenia. In support, a separate structural representation for the fingers has been proposed by previous authors (Goldenberg, 2000; Rusconi et al., 2014). This proposal comes from studies of finger agnosia, a disorder that is caused by focal cortical lesions and consists of the inability to determine the spatial relationship of the fingers relative to each other (Gainotti et al., 1972; Gerstmann, 1940; Goldenberg, 2000; Kinsbourne & Warrington, 1962; Rusconi et al., 2010). The neurological literature has also demonstrated a double-dissociation of finger agnosia and autotopagnosia (Goldenberg, 2000). Further support for this distinction between finger and body structural representations comes evidence from functional brain imaging studies that show several different brain areas underlie the proposed structural representations; the left anteromedial inferior parietal lobule (amlIPL) is the main site activated during an intermanual version of the in-between task (Rusconi et al., 2014), while the left superior parietal cortex (Corradi-Dell'Acqua et al., 2008; Corradi-Dell'Acqua et al., 2009; Felician et al., 2004) and the left posterior intraparietal sulcus and angular gyrus (Bonda et al., 1995; Corradi-Dell'Acqua et al., 2009; Ehrsson et al., 2004; Le Clec'H et al., 2000; Rusconi et al., 2014) are activated during internal representation of body parts.

A fourth explanation is that the alteration of body structural description could be a decrease in visuospatial acuity of the information contained therein. Functional consequences of a reduction in visuospatial acuity in people with schizophrenia would be that judgements of body part positions that require a high degree of acuity, such as the distances between the fingers as assessed by the in-between task, would be affected and more errors would be made. In contrast, judgements on a larger scale that do not require much precision, such as at the level of whole body parts, would not be affected by a selective impairment in fine-detailed acuity. This proposal is supported by previous findings of reductions in the fine-grain detail of generalised visuospatial acuity in people with schizophrenia, as assessed by tasks of spatial processing (Badcock, Badcock, Read, & Jablensky, 2008; Glahn et al., 2003; J. Lee & Park, 2005; Tek et al., 2002).

The results of the current study give little indication as to which of these four explanations is most likely. Future research could determine if the changes in body structural description are due to a dissociation of finger and body structural representations or decreased visuospatial acuity by assessing performance on a visuospatial acuity task and correlating it with performance on the in-between and
matching body parts by location tasks, and including a larger variety of tasks assessing judgements of the spatial relationship between body parts.

4.4.2 Body structural description in passivity symptoms

Contrary to our hypothesis that there would be greater alterations of body structural descriptions in people with any history of passivity symptoms, there were no significant differences between the groups of people with schizophrenia. Given the analysis of the in-between task on the broader schizophrenia group found people with schizophrenia made more errors than controls, it is likely that body structural description alterations are a ‘trait’ in schizophrenia, rather than associated with any symptom grouping. The brain sites most closely identified with the function of body structural description (the left posterior parietal cortex, left amIPL, left posterior intraparietal sulcus and angular gyrus) have not been implicated in functional brain imaging studies of passivity symptoms (Franck et al., 2002; Shergill et al., 2014; S. A. Spence et al., 1997). The absence of a common brain site that underlies both passivity symptoms and body structural description may explain why this body representation is not selectively altered in people with passivity symptoms.

4.4.3 Alterations of body image are common to schizophrenia

Alterations of body image were found in all people with schizophrenia in the current study. These included a perceived loss of the physical boundaries of the body, a reduction in the perceived intensity of the self and increases in experiences of body parts being both larger and smaller. This finding replicates previous findings of body image alterations as assessed with the body distortion questionnaire (Priebe & Röhricht, 2001; Röhricht & Priebe, 1996, 2002) and the rubber hand illusion (K. T. Graham et al., 2014; Peled et al., 2003; Peled et al., 2000; Thakkar et al., 2011). Importantly, the current data comes from the same samples in which body image, body agency and body schema alterations have previously been found (K. T. Graham et al., 2014; Graham et al., in preparation). These data lend further support to the hypothesis that schizophrenia is fundamentally a disorder of disturbances of the self by demonstrating that one body representation, body image, is altered in people with schizophrenia.
4.4.4 Body image distortions are worsened during current experience of passivity symptoms, boundary loss of the body is a trait of passivity symptoms

Responses to the body distortion questionnaire were also differentiated between cohort subgroups classed on their history of passivity phenomena; the highest endorsement of items detailing experiences of depersonalisation and unusually small or large body parts was by participants in the Current group, followed by Past and Never (no significant difference between these two groups) and then Controls. For the subscale ‘boundary loss’, the Current group reported the highest experiences, followed by the Past, Never and Control groups.

Previous work with the projected hand illusion demonstrated that body representations are altered in passivity symptoms (K. T. Graham et al., 2014). The current study provides further support for distortions of body representations, particularly body image, in passivity symptoms. For the subscales of ‘depersonalisation’, ‘large’ and ‘small’ body size changes, people in the Current group reported higher occurrences of these experiences but this did not appear to be a trait-like feature of passivity symptoms, but rather an elaboration of self-disturbances common to schizophrenia. The neuropathological mechanisms behind such an elaboration has been detailed by previous authors; in the period leading up to, and during, an acute stage of psychosis there is aberrant salience conferred to familiar or irrelevant stimuli (Howes & Kapur, 2009; Kapur, 2003; Kapur et al., 2005). This aberrant salience disrupts the usual experience of the self, leads to distancing or estranging from these basic self-processes and a fragmentation of self-experience (Nelson et al., 2014a, 2014b; Sass & Parnas, 2003). Presumably, the clinical state of the individuals in the Current group led to more experiences of body-related disturbances.

The changes reported in the ‘boundary loss’ subscale appear to be a trait of passivity symptoms; the Past group reported experiences of boundary loss at intermediate levels to the Current and Never groups. Given that we have found increased experiences of disembodiment during the projected hand illusion in both Current and Past groups (K. T. Graham et al., 2014), it was also expected that ratings of depersonalisation would be higher in the two passivity groups; this was not the case in the current study. There are two important candidate brain regions whose dysfunction may underlie the body representation changes and boundary loss experiences in passivity symptoms. The right parietal cortex has been found to be hyperactivated (Franck et al., 2002; Ganesan et al., 2005; S. A. Spence et al., 1997), and the insular cortex hypoactivated (Brüne et al., 2008; Farrer et al., 2004), in people with passivity
symptoms. The right parietal cortex is normally activated during dynamic updating of spatial coordinates with changes in the environment due to voluntary movements (Colby & Goldberg, 1999) and the insular cortex has been associated with body awareness generally (Craig, 2002, 2009), body ownership (Devue et al., 2007; Karnath & Baier, 2010) and egocentric representation (Fink et al., 2003). It is feasible that alterations in the way these brain regions contribute to body image result in ambiguity in the perception of the physical boundaries of the body. This is potentially a very important feature that is required for the development of passivity symptoms; the perceived breakdown of the physical boundaries of the body could lead to the subjective experience of vulnerability to external influences.

4.4.5 Consequences of alterations in body representations

The consequences of reduced acuity of the body structural description could conceivably lead to an exacerbation of other body representation changes that have been observed in schizophrenia and passivity symptoms. It has been demonstrated in healthy subjects that body image is highly dependent upon synchronous multimodal information (de Vignemont, 2010, 2011) and also receives considerable input from the body structural description (Auclair & Jambaqué, 2014). As such, any conflict or ambiguity in visuospatial information about the body could lead to difficulties in determining the body’s boundaries. A consequence of this can be seen in the changes in body image in schizophrenia that occur during the rubber hand illusion. In this illusion, the ‘other’ hand is displaced spatially from the body and, in healthy controls, this displacement is only overcome (that is, the illusion is only experienced) by both synchronous tactile and visual stimulation together (Botvinick & Cohen, 1998). In order for the other hand to be embodied, it must first be integrated into the body image (Longo et al., 2009; Tsakiris & Haggard, 2005). If people with schizophrenia are worse at determining the spatial relationship of their body parts to the rest of the body, the spatial conflict may be lessened or reduced, external objects outside the boundaries of the body may be embodied and so the illusion becomes easier to experience (K. T. Graham et al., 2014; Peled et al., 2003; Peled et al., 2000; Thakkar et al., 2011). Reduced acuity of the body structural description could also contribute to impairments in both predictive motor processes and post-hoc agency inferences (see Moore & Fletcher, 2012; Moore et al., 2012; Synofzik et al., 2008), the former by giving imprecise spatial information about body parts and the latter by causing ambiguity over the spatial location of body parts in relation to the body.
4.4.6 Limitations

The first limitation of the study is that the matching body parts by location task was not sensitive enough to detect changes in body structural description, even though it has been used previously in other clinical groups (Schwoebel & Coslett, 2005). It is possible that more trials could have been used, but the difficulties of working with this clinical population prevented us from doing so. The second potential limitation is that the Current group may simply have had a bias of responding positively to all questions, rather than agreeing to questions because they actually have these experiences. That this group differentially responded to the subscales is an argument against this possibility.

Acknowledgements

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Preface to chapter 5

After demonstrating that i) people with passivity symptoms have trait-like alterations of body schema (chapter three) and body image (chapter three and four), ii) there are alterations of body structural description general to schizophrenia (chapter four) and iii) there were changes in the experience of agency during the PHI general to schizophrenia (chapter three), the aim of the next experiments was to examine another marker of agency, intentional binding.

Intentional binding was of particular interest as it is a measure of the efficacy of efferent signals to affect downstream processes, a deficiency of which has been implicated in passivity symptoms. The technique chosen to assess intentional binding, the interval estimation procedure, has been used extensively in investigations of agency in university undergraduate samples, but not in healthy controls that have been age-matched to a group of people with schizophrenia. The interval estimation procedure also assesses general time perception on temporal scales of motor processing. The aim of chapter 5 was to provide an investigation of this procedure, using active and passive movements, in the current sample of healthy controls and to assess the effects of demographic variables, particularly age, on intentional binding. As with chapter 2, there was also the opportunity to investigate the relationship of psychosis-like experiences to the body representation of interest (body agency).

It was hypothesised that people would report intentional binding (intervals after active movements perceived as less than intervals after passive movements) and that increasing age would be associated with an increase in the perception of the length of the interval. It was also hypothesised that increasing psychosis-like experiences would be associated with an increase in intentional binding and would perceive the interval to be shorter, across both active and passive conditions.
Chapter 5 - Intentional binding or perceptual repulsion? Binding in a general population sample decreases with age and increases with psychosis-like experiences


Abstract

The sense of agency is an essential part of human experience. One aspect of agency, intentional binding, is the subjective contraction of time between a willful, voluntary action and the sensory consequences of that action. Previous studies of intentional binding have mainly been conducted with undergraduate samples. The present study utilized a 200-600 ms interval estimation task, with active and passive movements, to assess intentional binding in a community sample (mean age = 44.6, range = 21 – 60) in whom psychoses-like experiences (PLE) were also assessed. Intentional binding, assessed with a 200 ms interval between an action and a subsequent tone, was observed in younger, but not older, adults. Independent of age, increasing PLE were associated with increased intentional binding at the 200 ms interval. Participants reported the perceived interval to be greater for active movements in comparison to passive movements (perceptual repulsion) at 400 and 600 ms intervals, independent of age. There was an overall decrease in the perceived length of the interval associated with ageing, independent of movement condition, and an overall increase in the length of the perceived interval associated with an increase in PLE, independent of age. We propose that ageing decreases, while PLE increase, the size of the temporal window in which an action and its consequence/s can be bound. Finally, we propose that increasing age is associated with a slowing down, and PLE with a speeding up, of an internal pacemaker, one that may be regulated by dopaminergic transmission.
5.1 Introduction

One of the most fundamental aspects of human experience is the sense of agency; the subjective experience that “I did that”. The sense of agency extends to both external events (“I turned on that light”) and internal events (mostly thoughts and actions). ‘Intentional binding’, or the subjective contraction of time after voluntary, relative to involuntary, actions, interacts in a complex manner with the sense of agency but, under typical “everyday” conditions is an important contributor to the sense of agency (Haggard et al., 2002; Moore & Obhi, 2012). Intentional binding has been investigated mainly in young university undergraduates, and the generality of this phenomenon in the general community is unclear. In addition, given that alterations in the experience of agency are core clinical features of psychotic disorders, it is likely that individual differences on the continuum of psychosis proneness may also affect performance on such tasks.

Haggard and colleagues (2002), made the pioneering observation that the perceived interval between an action (pushing a button) and a sensory consequence (a tone played at a short interval after) was decreased when actions were intentionally produced relative to non-intended (passive) actions. This subjective contraction of time after active movements was termed intentional binding. This binding is viewed as an indirect indicator of the sense of agency and it has been confirmed that intentional binding occurs in situations where conscious feelings of agency are experienced (Ebert & Wegner, 2010). Intentional binding is also generalized across multiple sensory modalities, including visual, proprioceptive and auditory cues (Cravo, Claessens, & Baldo, 2009; Ebert & Wegner, 2010; Engbert et al., 2008).

Although the exact bottom-up afferent and top-down psychological processes are not well understood, it has been confirmed that intentional binding is initiated by an efferent motor signal. Engbert and colleagues (2008) demonstrated that intentional binding is present only when an action is self-made and not after induced (passive) actions or after observing actions of others. A study employing repetitive transcranial magnetic stimulation (rTMS) found that inhibition of the pre-supplementary motor area, an area involved in the preparation and initiation of actions and highly likely to support predictive components of intentional binding, impeded intentional binding, while rTMS of the primary motor cortex and an area of the primary somatosensory cortex did not inhibit intentional binding (Moore, Ruge, et al., 2010).

The actual mechanism by which efferent motor signals trigger intentional binding occurs is still unclear; there is evidence that efferent motor signals cause a brief
slowing down, then compensatory partial speeding up, of an internal time-keeping mechanism (Wenke & Haggard, 2009). As the internal clock slows, less time is perceived to have occurred between the action and consequence. The result of this is a shorter, and possibly more reliable, perceived interval between action and consequence, allowing discrimination between internal self-made and passive movements and actions (Eagleman & Holcombe, 2002; Wenke & Haggard, 2009).

Two methods have been used to assess intentional binding. The first, introduced by Libet and colleagues (1983), is known as the Libet clock method. In this task, participants use a moving clock hand to estimate the time at which an action, or a tone subsequent to the action, has occurred. These trials are then compared to further trials where actions occur without tones and where tones occur without actions. One shortcoming of this task is that it requires participants to focus on either actions or consequences, but not both simultaneously (Engbert et al., 2008; Moore, Lagnado, et al., 2009). The second method, the interval estimation procedure, avoids repetitions by requiring participants to directly estimate the time between an action (active or passive) and a sensory consequence, so that actions and consequences are compared in the same trial. This latter procedure is commonly used in agency studies, where findings show a reduction in the perceived time between actions and their consequences after active, but not passive, movements (Cravo et al., 2009; Ebert & Wegner, 2010; Engbert et al., 2008; Moore, Wegner, & Haggard, 2009; Wenke & Haggard, 2009).

There is accumulating evidence that mental events that are reliant on the integration of motor commands and/or afferent sensory information are directly impacted by changes in internal timing. This is convincingly demonstrated on the near-impossibility of the self-tickle phenomena (Blakemore, Wolpert, et al., 2000) and on tasks such as the rubber hand illusion (Botvinick & Cohen, 1998), where the illusion is highly dependent upon the precise timing of conflicting visual and tactile information. In relation to intentional binding, timing appears to play an important role as some studies have found that it occurs strongest when the interval between an action and its consequence is below 200-250 ms and subsequently weakens with increasing interval length (Ebert & Wegner, 2010; Haggard et al., 2002), while others have found that intentional binding is consistent across 100, 400 and 700 ms intervals (Cravo et al., 2009; Moore, Wegner, et al., 2009; Wenke & Haggard, 2009). The sense of agency over actions also decreases with increasing interval between an action and an outcome (Ebert & Wegner, 2010; Sato & Yasuda, 2005). From this, it would be expected that inter-individual differences or biases in internal timing mechanisms could increase or reduce
the perceived interval between an action and a consequence, and subsequently influence the attribution of agency.

A limitation of the current literature is that studies have been predominantly conducted in highly selected samples (university undergraduate students, usually psychology students, and with a strong bias towards a narrow age range). The generalization of these findings to broader community samples, especially in older people, is unclear. It is known that internal timing mechanisms underlying the perception of intervals longer than 1 second undergo considerable change with ageing (Espinosa-Fernández, Miró, Cano, & Buela-Casal, 2003; Hancock & Rausch, 2010; Płotek et al., 2014). More specifically, older adults tend to under-produce these intervals and over-estimate the intervals between two events, indicating the speeding up of an internal pacemaker i.e. a faster pacemaker accumulates more units of time in a given period. However, little research has been performed on the time scales that are more typical of motor commands and sensory feedback. Given the current research indicating an increase in the speed of the internal pacemaker with age, we hypothesized that, during an intentional binding task, the interval between action and consequence would be perceived to be further apart with increasing age, corresponding to a greater accumulation of time in this period.

Issues of timing and the sense of agency are particularly relevant for the study of schizophrenia, as people with the illness often have an impaired sense of agency (Gallagher, 2004; Jeannerod, 2009; Kircher & Leube, 2003) and distorted timing mechanisms (for a review, see Waters, 2013), particularly so in individuals with passivity symptoms (K. T. Graham et al., 2014). A useful analog of schizophrenia for research is the measurement of psychotic-like experiences (PLE) in healthy people. These studies overcome some limitations of researching schizophrenia directly, such as differing illness severity and medication levels. PLE are similar phenomenologically to some positive symptoms of schizophrenia but are not severe enough to constitute a diagnosis of the disorder (Hanssen, Bijl, Vollebergh, & Van Os, 2003; Kendler, Gallagher, Abelson, & Kessler, 1996; Meehl, 1962; Venables, Wilkins, Mitchell, & Raine, 1990). The presence of PLE signifies a subgroup of healthy people who may be at a higher-risk of developing the disorder and who have similar behavioral and cognitive characteristics as people with schizophrenia, albeit in a muted way (Chapman et al., 1994). PLEs occur relatively frequently in healthy individuals, with the lifetime prevalence estimated to be between 10-15% (Poulton et al., 2000; van Os et al., 1999). People with schizophrenia demonstrate abnormalities of intentional binding on the Libet
clock task, such that the interval between actions and their consequence are perceived to be even closer together in time (Haggard et al., 2003). Another study with the Libet clock method found that people with a putative psychosis prodrome (n = 30) experienced a numerical, but not statistically significant, increase in intentional binding (Hauser, Knoblich, et al., 2011). Given these results, we predicted that people with PLE would experience greater intentional binding on active movement trials. It was previously reported that, in the rubber hand illusion, people with schizophrenia with pronounced deficits in the sense of agency were not sensitive to the delay between the brush strokes and visual feedback, i.e. they experienced the illusion even after a 500 ms delay (K. T. Graham et al., 2014). We hypothesized that this is because this patient group has a distorted timing mechanism such that events are perceived as closer together in time. In line with these findings, we hypothesized for the current study that there would also a reduction in perception of the time between the action and tone in people who reported a higher level of PLEs.

The aim of the current study was to use an intentional binding task (interval estimation procedure) to assess the sense of agency in a sample of individuals recruited from the community (age range = 21 – 60). Given the literature on intentional binding effects, it was hypothesized (i) that, at 200 ms, participants would perceive time intervals linked to active movements as shorter than time intervals linked to passive movements. Further, the second hypothesis predicted (ii) that intentional binding would decrease at 400 and 600 ms intervals. In relation to age, we hypothesized (iii) that increasing age would be associated with a reduction in the perceived interval across 200, 400 and 600 ms intervals, independent of movement condition. Finally, in relation to PLE score, it was hypothesized (iv) that increasing PLE score would be associated with an increase in intentional binding at 200 ms and (v) that increasing PLE would also be associated with a reduction in the perceived interval, across all intervals.

5.2 Methods

5.2.1 Participants

Community individuals (24 males and 24 females) took part in this study (see Table 5.1 for demographics). 43 of the participants were able to complete all testing and so were included in the analysis. Participants were recruited through community advertising. Exclusion criteria for all participants included organic brain disease, substance-use disorder or a diagnosis of a schizophrenia-spectrum disorder or psychosis. Participants were screened for all major psychiatric disorders using the Mini-
International Neuropsychiatric Interview (MINI). The study protocol was explained to all participants and written informed consent was obtained. All protocols of the study conformed to the appropriate regulations of, and were approved by, the North Metropolitan Mental Health Service Human Research Ethics Committee. Participants were reimbursed for their time.

### Table 5.1. Demographic and neuropsychological (Wechsler Test of Adult Reading, WTAR; Psychosis-like experiences, PLE) information of participants (n=43). Data are mean ± SEM.

<table>
<thead>
<tr>
<th>Sex (M/F)</th>
<th>Age (years)</th>
<th>Age (range)</th>
<th>Years Education</th>
<th>WTAR</th>
<th>PLE (Total Score/24)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All subjects</td>
<td>23/20</td>
<td>44.6 ± 1.7</td>
<td>21 - 60</td>
<td>13.8 ± 0.3</td>
<td>104 ± 2.02.44 ± 0.35</td>
</tr>
<tr>
<td>Younger (n = 12)</td>
<td>3/9</td>
<td>29.0 ± 2.1</td>
<td>21 - 40</td>
<td>14.0 ± 0.55</td>
<td>106 ± 5.42.25 ± 0.60</td>
</tr>
<tr>
<td>Older (n = 31)</td>
<td>17/14</td>
<td>50.7 ± 0.98</td>
<td>41 - 60</td>
<td>13.7 ± 0.49</td>
<td>105 ± 2.12.52 ± 0.43</td>
</tr>
</tbody>
</table>

#### 5.2.2 Psychosis-like experiences (PLE) questionnaire

This screen assessed the lifetime-experience of psychosis-like experiences (Jablensky et al., 2000) and consisted of six questions pertaining to delusional mood (1 item), delusions of control (1 item), persecutory delusions (2 items) and hallucinosis (2 items). The questions were rated on a 5-point scale ranging from 0 (never) to 4 (often). Ratings on each item were then summed for each participant, for a total possible score of 24 (PLE score).

#### 5.2.3 Materials & Procedures

A questionnaire assessing age, sex, years of education and self-reported medical problems was administered to all participants. A test of premorbid intelligence (Wechsler Test of Adult Reading; WTAR), demographic information and the PLE questionnaire ratings were all collected before the intentional binding procedure.

The intentional binding task (adapted from Engbert et al., 2008) was delivered on the software EPrime (v 1.2). The participant was asked to judge the duration of time between an action (a button press on a computer keyboard) and a subsequent stimulus (a 100 ms, 1 kHz tone played through headphones).

There were two movement conditions: in the Active condition, the participant rested their finger in a brace on the spacebar and intentionally pushed the spacebar. In
the Passive condition, the participant had their finger attached to the brace connected to the spacebar. A wire was connected to the brace from beneath the keyboard (entirely controlled by the experimenter and not visible by the participant) that depressed the spacebar. The order of conditions was counter-balanced across participants; participants were assigned a presentation order in a pseudorandom manner.

Before each movement condition, participants were told to report their answer in milliseconds and that every trial would be less than 1 second and greater than 0 s, and just to guess if they were not sure. They were reminded that 1 s = 1000 ms, 0.5 s = 500 ms etc., and that any answer between 1 and 999 was acceptable. Before each condition, the participant was also instructed to ensure they were looking at the spacebar and their finger every trial. Care was taken to ensure participants followed this instruction for each trial. Each condition was presented in a single block and consisted of 45 trials. The interval between the button press and the onset of the tone was either 200, 400 or 600 ms. Thus, each interval was presented 15 times per block. Trials began with a 2 cm black cross in the middle of a white background on a digital computer monitor. When the participant was ready, they pressed the spacebar on the keyboard. The cross disappeared immediately and was followed by a blank screen for the duration of the interval. One second after the interval had elapsed, a message appeared on the screen asking the participant to “Estimate the time, in milliseconds, the tone was delayed after you pressed the spacebar”. The participant gave a verbal response at their own pace, and the response was entered into the computer by the experimenter. A blank white screen then appeared for 1000 ms before the cross re-appeared and the next trial began. No practice trials or reference times were given as we were interested in biases between movement conditions and not accuracy of the estimations.

5.3 Results
5.3.1 Statistical methods

All statistical analyses and figures were completed using the statistical software R (version 3.0.1; R Core Team, 2012), and the packages ‘nlme’ (version 3.1-113; Pinheiro et al., 2013) and ‘car’ (Fox & Weisberg, 2011). Analyses were performed using linear mixed-effects models with perceived interval as the dependent variable, movement condition (Active or Passive), interval (200, 400 or 400 ms), age (years) and PLE score (total score / 24) as the fixed effects. The random effects term had random participant effects with a nested movement condition by interval interaction. Sex, years of education and WTAR were included as covariates, however, none were significant.
and were removed from the analysis. Where analysis of deviance (ANODEV) on the parameters of the model revealed significant differences, linear treatment contrasts were performed. Contrasts were corrected with the Holm-Bonferroni method. Alpha was set at 0.05.

Table 5.2. Results of the ANODEV for the linear-mixed effects model describing the perceived interval between an action and a tone played through headphones. The action was either active or passive (Movement Condition) and the tone was 200, 400 or 600 ms after the action (Interval). Age (years) and the sum of positive responses (/24) to a questionnaire assessing psychosis-like experiences (PLE score) were also included as fixed effects.

<table>
<thead>
<tr>
<th></th>
<th>Df</th>
<th>Nf</th>
<th>Wald χ²</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movement condition</td>
<td>1</td>
<td>195</td>
<td>3.78</td>
<td>0.05 *</td>
</tr>
<tr>
<td>Interval</td>
<td>2</td>
<td>195</td>
<td>287</td>
<td>&lt; 0.0001****</td>
</tr>
<tr>
<td>Age</td>
<td>1</td>
<td>39</td>
<td>2.44</td>
<td>0.12</td>
</tr>
<tr>
<td>PLE score</td>
<td>1</td>
<td>39</td>
<td>0.46</td>
<td>0.50</td>
</tr>
<tr>
<td>Movement condition x Interval</td>
<td>2</td>
<td>195</td>
<td>4.29</td>
<td>0.12</td>
</tr>
<tr>
<td>Movement condition x Age</td>
<td>1</td>
<td>195</td>
<td>2.11</td>
<td>0.15</td>
</tr>
<tr>
<td>Interval x Age</td>
<td>2</td>
<td>195</td>
<td>3.15</td>
<td>0.21</td>
</tr>
<tr>
<td>Movement condition x PLE score</td>
<td>1</td>
<td>195</td>
<td>0.61</td>
<td>0.43</td>
</tr>
<tr>
<td>Interval x PLE score</td>
<td>2</td>
<td>195</td>
<td>0.56</td>
<td>0.76</td>
</tr>
<tr>
<td>Age x PLE score</td>
<td>1</td>
<td>195</td>
<td>0.28</td>
<td>0.59</td>
</tr>
<tr>
<td>Movement condition x Interval x Age</td>
<td>2</td>
<td>195</td>
<td>0.20</td>
<td>0.90</td>
</tr>
<tr>
<td>Movement condition x Interval x PLE score</td>
<td>2</td>
<td>195</td>
<td>1.52</td>
<td>0.47</td>
</tr>
<tr>
<td>Movement condition x Age x PLE score</td>
<td>1</td>
<td>195</td>
<td>0.10</td>
<td>0.75</td>
</tr>
<tr>
<td>Interval x Age x PLE score</td>
<td>2</td>
<td>195</td>
<td>6.12</td>
<td>0.047*</td>
</tr>
<tr>
<td>Movement condition x Interval x Age x PLE score</td>
<td>2</td>
<td>195</td>
<td>0.16</td>
<td>0.92</td>
</tr>
</tbody>
</table>

* p < 0.05, ** p < 0.01, *** p < 0.001, **** p < 0.0001

5.3.2 Intentional binding at 200, 400 and 600 ms
The results of the ANODEV can be seen in Table 2. As expected there was a main effect of interval with perceived intervals increasing as the actual interval increased. There was also a significant main effect of movement condition. However, contrary to our hypotheses (i) and (ii), as can be seen in Figure 5.1, passive movements were perceived to be shorter than active movements.

![Figure 5.1](image_url)

**Figure 5.1.** Perceived length (ms) of an interval between an action (the pushing of a button on a keyboard) and a subsequent tone played through headphones for active and passive actions with intervals of 200, 400 and 600 ms between the action and tone. Data are means ± SEM.

The main effects of PLE score and age were not significant. No two-way interactions were significant. There was a significant interaction between interval, PLE score and age. The interaction contrasts showed that the slopes of age and PLE score at the 200 ms interval was significantly different from the slope of age and PLE score at 600 ms ($p = 0.05$), but there were no significant differences in the slopes of age and PLE score between at 200 and 400 ms, and at 400 and 600 ms ($p = 0.57$ and 0.13, respectively). As can be seen in Figure 5.2, this interaction demonstrates that increasing age was associated with a decrease in the perceived time of the interval, and that this effect was greater with increasing actual intervals. In contrast, increased PLE score was associated with an increase in the duration of the perceived interval, and this effect was consistent across intervals.
As such, the perceived time of the interval for each individual was a function of both the age of the participant and their PLE score. The four-way interaction between the four fixed effects was not significant.

5.3.3 Intentional Binding at 200 ms interval

Given the finding of the interval being perceived as shorter after passive, compared to active, movements, and not vice versa as expected, it was decided that a second ANODEV would be performed focusing on just the 200 ms interval data; this interval was chosen as findings of intentional binding have been most consistent at shorter intervals. Further, to more clearly illustrate the effect of age found in the previous section, the sample was split into groups of under 40 years of age (‘Younger’, n = 12) and over 40 years of age (‘Older’, n = 31). The demographics of each can be seen again in Table 1. This ANODEV revealed no main effect of movement condition ($F(1, 39) = 2.79, p = 0.10$), age ($F(1, 39) = 2.77, p = 0.10$) or PLE score ($F(1, 39) = 2.79, p = 0.10$).

![Figure 5.2](image-url)

**Figure 5.2.** The relationship between age of the participant and total psychosis-like experiences score and the perceived interval (ms) between an action (the pushing of a button on a keyboard) and a subsequent tone played through headphones with intervals of (A) 200, (B) 400 and (C) 600 ms between the action and tone. The lines are the linear relationship between age or PLE score and the perceived interval, extracted from the linear mixed-effects model. Filled circles – data plotted by PLE score. Empty circles – data plotted by age. X-axis on top of plotting area represents the range of PLE score; the x-axis on the bottom of the plotting area represents the range of age.

5.3.3 Intentional Binding at 200 ms interval

Given the finding of the interval being perceived as shorter after passive, compared to active, movements, and not vice versa as expected, it was decided that a second ANODEV would be performed focusing on just the 200 ms interval data; this interval was chosen as findings of intentional binding have been most consistent at shorter intervals. Further, to more clearly illustrate the effect of age found in the previous section, the sample was split into groups of under 40 years of age (‘Younger’, n = 12) and over 40 years of age (‘Older’, n = 31). The demographics of each can be seen again in Table 1. This ANODEV revealed no main effect of movement condition ($F(1, 39) = 2.79, p = 0.10$), age ($F(1, 39) = 2.77, p = 0.10$) or PLE score ($F(1, 39) = 2.79, p = 0.10$).
0.61, \( p = 0.44 \). The age by PLE score interaction (\( F(1, 39) = 0.70, p = 0.40 \)) and the three-way movement condition by age by PLE score interaction (\( F(1, 39) = 1.89, p = 0.17 \)) were not significant. There were two significant interactions. The first, between age and movement condition (\( F(1, 39) = 8.24, p = 0.004 \)), indicated that younger people perceived the interval between action and the tone for active movements to be shorter than for passive movements, but there was no significant difference between the conditions reported by older participants (see Figure 5.3; raw data can be seen in Figure 5.4a). The second interaction, between PLE score and movement condition (\( F(1, 39) = 12.0, p = 0.005 \)), indicated that as PLE score increased, participants perceived the interval to be less after active movements, compared to passive movements (see Figure 5.4b).

![Figure 5.3](image)

**Figure 5.3.** Perceived interval (ms) between an action (the pushing of a button on a keyboard) and a subsequent tone played through headphones 200 ms later after passive and active movements for participants below the age of 40 years (Younger, \( n = 12 \)) and above 40 years (Older, \( n = 31 \)). Data are means ± SEM. ***, \( p < 0.0001 \).

### 5.4 Discussion

The aim of the current study was to assess intentional binding after active and passive movements in a general community sample using an interval estimation procedure. It was hypothesized that, at 200 ms, the interval after active movements
would be perceived as shorter than passive movements, and that this effect would change as a function of increasing psychosis-like experience (PLE scores). Second, we hypothesized that this subjective contraction of time would decrease at 400 and 600 ms intervals. In contrast to our hypothesis, intentional binding was not present at 200 ms; further analysis revealed that it was only present in younger, but not older, individuals. Furthermore, intentional binding varied as a function of PLE scores with increasing psychosis proneness being linked to greater intentional binding. The overall perception of the interval (independent of the movement condition), was a function of both PLE and age with increasing age associated with a decrease in the reported perception of time between the action and tone, and increasing PLE score associated with an increase in the perceived interval. Our results indicate that there are two clear processes involved in intentional binding and time perception, which are separable, although overlapping.

**Figure 5.4.** The relationship between perceived interval (ms) between an action (the pushing of a button on a keyboard) and a subsequent tone played through headphones 200 ms later, with (A) age of the participant and (B) total psychosis-like experiences score. The lines are the linear relationship between (A) age and (B) PLE score and the perceived interval, extracted from the linear mixed-effects model.

### 5.4.1 The effects of age on intentional binding at 200 ms

An age effect was found for intentional binding at the 200 ms interval; at this interval increasing age was linked to a decreased differentiation between active and passive movement conditions. That is, the subjective compression of temporal intervals between a voluntary action and its consequence was present in younger individuals but
diminished with increasing age. This appears to be the first demonstration of age effects on intentional binding.

The current findings in younger adults replicates that of other studies, which have primarily used undergraduate students with a mean age of less than 30, on intentional binding tasks at intervals of 100 or 200 ms (Cravo et al., 2009; Ebert & Wegner, 2010; Engbert et al., 2008; Moore, Wegner, et al., 2009), and in studies using the Libet clock method with an interval of 250 ms (Haggard et al., 2002; Moore & Haggard, 2008; Tsakiris & Haggard, 2003). However, the compression effect triggered by voluntary actions was largely absent in the older age group at this interval, suggesting that age of participants strongly influences the presence of intentional binding at short intervals.

There are three possible explanations for this novel finding. The first concerns the well-established decreasing levels of dopamine in the ageing brain (Carlsson & Winblad, 1976; Ponzio, Brunello, & Algeri, 1978; Ponzio et al., 1982; Stoessl, Martin-Iverson, Barth, Dourish, & Iversen, 1989). In addition, the activity of Catechol-O-methyl transferase in the human prefrontal cortex, a key enzyme in regulating extracellular dopamine levels, is low until the late twenties to early thirties when the levels increase to a level that is stable for the majority of adulthood (Tunbridge et al., 2007).

Dopamine plays a clear role in motor-perceptual learning (Dinse, Ragert, Pleger, Schwenkreis, & Tegenthoff, 2003; Hosp, Pekanovic, Rioult-Pedotti, & Luft, 2011; Molina-Luna et al., 2009; Nitsche et al., 2004), apparently widening the window of associability in which two events can be bound (Albrecht et al., 2011; Seitz & Dinse, 2007). Perhaps, due to higher dopamine levels in younger people, there is a wider temporal window during which intentional binding can occur. By contrast, decreasing dopaminergic levels in older people would reduce the window of associability so events must be closer together than 200 ms for intentional binding to occur. This hypothesis can be tested by using shorter intervals than used in the present study.

A second possibility is that the age effects may be due to a gradual decrease in acuity of proprioception associated with ageing (Adamo et al., 2009; Goble et al., 2009). Ageing is also linked to a decrease in the reliability of proprioceptive cues in a rubber hand illusion task (K. T. Graham, Martin-Iverson, Holmes, et al., 2015). If proprioception becomes less reliable with ageing, source monitoring becomes more difficult as it becomes more difficult to predict the outcomes of intentional movements. In order to compensate for these changes in proprioceptive reliability, it is possible that
the action and tone have to be closer together for the person to experience the tone as being caused by their action.

A final possible explanation is that the processes underlying intentional binding are mediated by Bayesian learning. Bayesian-styled learning is thought to be critical to sensorimotor integration and perceptual learning (Albrecht et al., 2011; Armel & Ramachandran, 2003; de Vignemont, 2010; K. T. Graham, Martin-Iverson, Holmes, et al., 2015) and has also been implicated in the sense of agency (Moore & Fletcher, 2012). In this framework, two stimuli (sensory inputs and/or motor commands) are experientially bound together when the co-occurrence of these two stimuli has a high posterior probability, determined in part by spatial and temporal cues of the current stimuli and by an individual’s history of perceptual experiences (de Vignemont, 2010). The sensory consequences of actions generally occur within milliseconds of the physical action being performed (e.g. a button is depressed immediately as a finger pushes on it). As people age, there is an accumulating body of experience of such small intervals between actions and their sensory consequences. A consequence is that the association between actions and immediate consequences is made stronger with increasing age. Over time, this accumulation of learning would have the effect of reducing the window of time when a consequence can be bound to its causing action. This window of time may be less than 200 ms in people at the older end of the age range of the current study. This narrowing of the temporal window of associability is supported by findings in multisensory integration, not specifically agency, whereby infants have a very wide window of associability that begins to narrow during early childhood (Lewkowicz, 1996, 2000, 2010; Lewkowicz & Flom, 2014), but still stays relatively wide into adolescence (Hillock-Dunn & Wallace, 2012; Hillock, Powers, & Wallace, 2011) and doesn’t mature until well into older ages (Wallace & Stevenson, 2014). The underlying mechanism affected may be the motor command-initiated slowing down, and subsequent compensatory speeding up, of an internal clock (Wenke & Haggard, 2009). With increasing age, the length of the period that the pace of internal clock speeds up is reduced and/or the later period of compensatory speeding up of the internal clock is increased. Sensory consequences that then occur in, or just after, this time period will then not be subject to the compression of time indicative of intentional binding as was found in the current study.
5.4.2 Intentional binding across 200, 400 and 600 ms intervals, and the effect of age

There were two main findings of the current study across the three intervals (200, 400, 600 ms) employed. Firstly, we failed to support hypothesis (ii), as the perceived intervals between actions and tones were longer for active movements compared to passive movements across all intervals. Previous investigations have found intentional binding to weaken at longer intervals (Ebert & Wegner, 2010; Haggard et al., 2002) or for intervals to be perceived as less after active movements across all intervals (Moore, Wegner, et al., 2009; Wenke & Haggard, 2009). Secondly, increasing age was associated with a reduction in the reported length of the interval. This implies a slowing down of an internal pacemaker, in line with to our hypothesis (iii).

We believe that the current study is the first to report a comprehensive examination of intentional binding that found subjects reported intervals after active movements to be perceived as longer as intervals after passive movements. A similar finding may have been found by Haggard and colleagues (2003) in a smaller sample (n = 8) of community individuals of a similar age to the current study (mean = 42.2 years). This study, using the Libet clock method, found that this sample did not show subjective compression of the perceived time of an action’s consequence. Further analysis revealed that this may have been driven by two subjects showing lengthening of the perceived interval between actions and the subsequent tone.

The original intentional binding study by Haggard and colleagues using the Libet clock method (2002) found that, while the perception of an interval between an intended action and its consequence is decreased, the perception of an interval after an induced action (achieved through transcranial magnetic stimulation applied to the motor cortex) was independently increased. These authors argued that in this condition, after perceiving a consequence that could not feasibly be a product of a self-produced action, there is perceptual repulsion between the two events. This could be a possible explanation for the current findings such that consequences of an intended action that are perceived to have occurred too late to have been caused by the action are also repulsed. Therefore, perceptual repulsion could also be applicable to the consequences of movements that are sufficiently temporally displaced and not just those without an intentional efferent signal.

The current findings show that perceptual repulsion does not necessarily occur for all intervals. Rather, below a certain interval there is intentional binding and above this interval there is perceptual repulsion. Such a critical time period for more general multisensory integration (Wallace & Stevenson, 2014), the generation of agency
(Wegner & Wheatley, 1999) and the production of intentional binding (Ebert & Wegner, 2010; Haggard et al., 2002) has been demonstrated previously in other studies. The point where intervals in active and passive movements are perceived to be equal appears also to shift with age, the possible mechanisms of which were discussed with the findings at 200 ms intervals.

The second finding across the three intervals used was that increasing age was associated with a reported reduction in the perceived time between the button push and the tone, independent of movement condition. This implies that the internal clock for these timescales is slowed down (i.e. less time units accumulate in a given period and so the period is perceived to be shorter), not sped up as has been found elsewhere (Espinosa-Fernández et al., 2003; Hancock & Rausch, 2010; Plotek et al., 2014). As described earlier, dopamine levels decrease with age. Levels of dopamine activity also have direct, but complex, associations with the rate of the internal pacemaker. For instance, manipulations with dexamphetamine and selective dopamine blockers show increases and decrease in the speed of the internal clock, respectively, particularly for intervals less than 500 ms (Buhusi & Meck, 2002; Meck, 1986, 1996; Rammsayer, 1993, 1999, 2009). Given that ageing is associated with a decrease in dopamine activity, this presumably would result in a decrease in the speed of the internal clock. How does this then reconcile with previous findings of an increase in internal clock speed with ageing? Previous studies investigating ageing and time perception have investigated time periods of over 1s and there is strong evidence that the timing mechanisms for processes operating on scales of less than 500 ms are separate from those mechanisms involved with scales above 500 ms. Further, these mechanisms for less than 500 ms are predominantly modulated by dopamine activity (Rammsayer, 1999, 2009; Schultz, 2007). As such, it would appear there are opposing effects of age on separate timing mechanisms in adult humans.

The reduction in the perception of time for both movement conditions with increasing age did not appear to affect intentional binding. This may seem counter-intuitive as, if less time is perceived to elapse between an action and its outcome, it would be expected that binding would be greater as the probability of the outcome being caused by the action is greater. This supposition, however, conflates the sensorimotor predictions involved with intentional binding and retrospective agency judgments. It has been contended previously that the final experience of “I did it” is developed from a combination of predictive sensorimotor processes and retrospective analysis of sensory consequences, each of which have different underlying
neuropsychological mechanisms (Moore & Fletcher, 2012; Moore et al., 2012; Moore, Wegner, et al., 2009; Synofzik et al., 2008). As such, it is possible that intentional binding and time perception can both be affected by age independently.

5.4.3 Psychosis-like experiences (PLE) and intentional binding

In agreement with our hypothesis (iv), the current study also showed that PLE were linked to increased binding between voluntary movements and their sensory consequences relative to passive movements. However, we also found evidence contrary to hypothesis (v) in that increasing PLE scores were associated with an overall increase in the perceived interval between button press and tone, independent of movement condition.

Studies using the Libet clock method have reported a greater intentional binding effect in people with schizophrenia relative to healthy controls (Haggard et al., 2003) and a numerically, but not statistically significant, increase in intentional binding in people in the prodrome of schizophrenia (Hauser, Knoblich, et al., 2011). However, no studies have investigated intentional binding using the interval estimation procedure in people with schizophrenia or any of its correlates in healthy people. The current results appear to be the first demonstration of PLE being associated with increased intentional binding. In keeping with an explanation involving dopamine as performing a key role in motor-perceptual learning, intentional binding increases in PLE may be due to an increase in dopamine transmission in people with higher PLE scores. In addition to the well-known relationship of dopamine to schizophrenia, there are robust findings showing increases in the release of dopamine, higher synaptic dopamine concentrations and higher dopamine receptor occupation in people with PLE (Abi-Dargham et al., 2004; K. C. Chen et al., 2012; Gray et al., 1994; Howes et al., 2013; Soliman et al., 2007; Taurisano et al., 2014; Woodward et al., 2011). The presence of higher levels of dopamine in PLE may therefore cause a widening of the window of associability in which two events can be bound. In support of this proposition, it has been found that administration of dopaminergic medication in people with Parkinson’s disease causes an increase in intentional binding (Moore, Schneider, et al., 2010). Altered intentional binding mechanisms may also contribute to aberrant agency experiences that are characteristic of schizophrenia (Waters & Badcock, 2010). If the temporal window for binding is broadened, the possibility for unrelated stimuli to be bound is increased. Given the functional role of dopaminergic pathways in assigning salience to external stimuli, it becomes feasible for agency over an action to be aberrantly assigned such that
external cues become a possible source of body input. Symptoms of schizophrenia such as replacement of will and thought interference may involve this hyperassociability of cause and effect.

Increased time estimation in both active and passive conditions in PLE is also likely due to increased dopamine transmission, due to its effects on the internal pacemaker (Buhusi & Meck, 2002; Meck, 1986, 1996; Rammsayer, 1993, 1999, 2009); an increased rate of the internal pacemaker will result in more units of time accumulating in a given period and so an interval will be perceived as having been longer than it actually was.

5.4.4 Limitations

There were three limitations of the current study. The first was that five participants were unable to complete all the movement conditions and so were excluded from analysis. The second limitation was that subjective ratings of agency were not taken after each trial; doing so would have allowed the effects of age and PLE on intentional binding and the subsequent effects on agency to be assessed. Third, it has been demonstrated that additional perceptual signals can impede multimodal perceptual grouping and agency (Kawabe, Roseboom, & Nishida, 2013); it is possible that the outcomes of the button press may have been interfered with by elements of the procedure such as response prompts. Although care was taken to ensure participants focused on their hand and the key press, it is still possible that some participants were attending to the prompts on the screen. Finally, the sample size was moderate, although sufficient to obtain meaningful statistical differences.

5.4.5 Conclusions

An interval estimation task assessing intentional binding in a community sample found that intentional binding was present in younger people but decreased with age. An association with psychosis-like experiences was also found at the 200 ms interval, whereby increasing PLE score was associated with increased intentional binding. At 400 and 600 ms intervals, perceptual repulsion was found, whereby participants reported the perceived interval to be greater for active movements in comparison to passive movements. Finally, age was associated with a decrease in the perceived length of the interval, while PLE were associated with an increase in the perceived interval. These results indicate that there are two separate, but functionally overlapping, mechanisms underlying intentional binding and time perception. It is likely that
dopaminergic regulation of these mechanisms underlies the changes seen in both age and PLE.

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Preface to chapter 6

In previous chapters, alterations of body schema (chapter three), body image (chapter three and four) and body structural description (chapter four) were found in passivity symptoms of schizophrenia. In order to investigate body agency in passivity symptoms, the use of an interval estimation procedure assessing intentional binding, a key component of agency, in healthy controls was validated in chapter five. This chapter found that increasing age was associated with a decrease in intentional binding such that older adults reported perceptual repulsion at the intervals assessed. It was also found that increased psychosis-like experiences in healthy controls was associated with increased intentional binding. Having investigated the use of this procedure in community-based healthy controls, the aim of chapter six was to assess intentional binding using the interval estimation procedure in a group of people with schizophrenia, divided into subgroups based on their lifetime and current history of passivity symptoms.

This study divided the people with schizophrenia into two groups (Passivity + and Passivity -), not into the three groups as in chapter 3 and 4 (Current, Never and Past). The groups were segregated this way as, during the initial analysis, there were no significant differences between the Never and Past groups. These two groups were then collapsed into one (Passivity -).

Although we demonstrated the importance of age in timing processes in chapter 4, we were unable to include this variable in the analysis for chapter 5. The size of the samples of the study, particularly in the Passivity + group, precluded this possibility. This change is addressed in the discussion.

It was hypothesised that a decrease in intentional binding would be observed in the Passivity + group, an increase in intentional binding would be observed in the Passivity – group and both groups would report an overall increase in the perceived interval, independent of intentional binding effects.
Chapter 6 - When one’s sense of agency goes wrong: Absent intentional binding and reduction of perceived length of intervals in passivity symptoms in schizophrenia

Abstract

Individuals with passivity symptoms feel they are no longer in control of their actions, thoughts and other somatic experiences and often report these events to be under the control of an external agent. The dysfunctional mechanisms underlying passivity symptoms are poorly understood. Time perception and intentional binding are both linked to feelings of agency and have been shown to be altered in schizophrenia, with some evidence for more severe timing dysfunctions in passivity symptoms. The aim of this study was to assess time perception and intentional binding in 39 people with schizophrenia (n = 15 with, and n = 24 without passivity symptoms) and 43 healthy controls using an interval estimation procedure (200, 400 and 600 ms intervals between an action and a tone) with voluntary movements (active), passive movements (passive) and observed movements of another agent (other). Controls perceived intervals to be longer after active movements than after passive and other movements. People with passivity symptoms did not display action-modulation of time perception (no difference in perception of intervals between movement conditions), while those without passivity symptoms estimated intervals after active and observed movements to be longer than passive movements. Additionally, both clinical samples had significantly smaller increases in the perceived time of interval with increasing interval length. The results indicate time perception and intentional binding processes are altered in schizophrenia. In passivity symptoms, the weakened intentional binding may produce an overreliance on external cues and, together with reduced perception of intervals, lead to the subjective loss of agency.
6.1 Introduction

One of the key features of schizophrenia is an impairment of the ability to correctly discriminate between internally-generated and externally-generated events. Individuals with passivity symptoms display a particularly severe form of this characteristic feature and report a lack of normal sense of ownership for thoughts and actions, alongside the subjective experience that one’s will is replaced or influenced by some external agent. Despite strong phenomenological evidence (Wing et al., 1990), epidemiological and symptom cluster analyses (Carpenter, Strauss, & Muleh, 1973; Jablensky et al., 1992; Kimhy et al., 2005; McGorry et al., 1998), functional brain imaging evidence (Franck et al., 2002; Shergill et al., 2014; S. A. Spence et al., 1997), heritability evidence (Cardno et al., 2002) and neurocognitive theoretical frameworks (K. T. Graham et al., 2014; Maruff et al., 2003; Waters & Badcock, 2010) that indicate passivity symptoms are distinct from other positive symptoms, research into these symptoms remains relatively sparse.

The precise neurocognitive mechanisms that lead to passivity symptoms are poorly understood. Emerging evidence suggests that internal timing dysfunctions may contribute in a significant way to the self-disturbances in passivity symptoms (K. T. Graham et al., 2014; S. A. Spence, 1996; Waters & Jablensky, 2009). Timing mechanisms refer to the neurological and neuropsychological processes that dictate the internal experience of the flow of time, and play a key role in the coordination of neural circuits and events (Buhusi & Meck, 2005; Ivry & Richardson, 2002; Ivry & Spencer, 2004). Intact timing is necessary for a smooth orchestration and integration of motor, sensory and cognitive information (Artieda, Pastor, Lacruz, & Obeso, 1992; Mates, Müller, Radil, & Pöppel, 1994; Meck, 1996; Repp, 2005) in order for behaviour to be synchronised appropriately with the external environment that the behaviour is directed towards. In addition, precise synchronisation of movements relative to the external world is critical for generating a sense of self (relative to others) and for attributing agency (the sense that ‘I’ did it) (Elliott, Welchman, & Wing, 2009; S. A. Spence, 1996). Dysfunctions in these mechanisms, by contrast, may cause distortions in self-monitoring processes and subjective experiences of action causation (B. Martin et al., 2014).

6.1.1 Time perception in schizophrenia and passivity symptoms

Studies have demonstrated that the perception of time on scales typical of motor processes strongly influences if an action is perceived to be self-generated (Ebert &
Wegner, 2010; Sato & Yasuda, 2005) and in the processes involved in associating causation between mental and external events (Haggard et al., 2002; Wegner & Wheatley, 1999). People with schizophrenia (undifferentiated by symptoms) show wide-ranging changes in time perception, as shown using a range of methods and tasks across short and long durations (see Waters, 2013 for a review). A consistent finding is that people with schizophrenia perceive intervals less than 1 second to be shorter, relative to healthy controls (Carroll, Boggs, O'Donnell, Shekhar, & Hetrick, 2008; Elvevåg, Brown, McCormack, Vousden, & Goldberg, 2004; Elvevåg et al., 2003; K.-H. Lee et al., 2009; B. Martin, Giersch, Huron, & van Wassenhove, 2013; Papageorgiou et al., 2013; Rammsayer, 1990; Waters & Jablensky, 2009). However, it is not clear which dysfunctional mechanism underlies these changes in time perception. Typically, the findings of a reduction in the perceived time of intervals has been interpreted as alterations in the rate of an internal pacemaker; either a decrease in clock speed (e.g. Elvevåg et al., 2003; Rammsayer, 1990) or an increase in variability of that speed (e.g. Carroll et al., 2008; K.-H. Lee et al., 2009; Papageorgiou et al., 2013). An alternative explanation suggests that these changes are correlated to deficits in working memory that affect the accumulator stage of timing processes, rather than differences in an internal pacemaker (K.-H. Lee et al., 2009; Roy, Grondin, & Roy, 2012).

6.1.2 Significance of changes in internal timing processes

In relation to the functional significance of changes in time perception, Spence (1996) proposed that such changes in sensorimotor processes may result in the awareness of the actual movement preceding awareness of the intention to act in schizophrenia. This situation is contrary to the normal experience of self-generated actions, and may lead to experiences of passivity. Few studies have addressed this proposal of a more pronounced alteration of time perception in passivity symptoms.

Using the rubber hand illusion task, we recently demonstrated decreased sensitivity to a time delay of 500 ms in the multimodal sensory integration of (visual and tactile) events in a group of people with passivity symptoms (n = 20). More specifically, people with passivity symptoms continued to experience the rubber hand illusion (an increase in embodiment and feelings of agency over the ‘other’ hand) during asynchronous stimulation, when healthy controls and patients without passivity symptoms do not experience the illusion (K. T. Graham et al., 2014). We speculated that a disruption in internal timing causes these individuals to experience events to be closer together in time. In support, it was recently shown that people with passivity
symptoms perceived the interval between two external auditory stimuli to be shorter than healthy controls or people without passivity symptoms (Waters & Jablensky, 2009). Using a task which relied on self-other judgements based on visual feedback, Daprati et al., (1997) also demonstrated that people with passivity symptoms (n = 7) more often erroneously reported that an image of a hand performing a movement on a screen in front of them was their own, both when that hand was someone else’s hand performing a movement different from the subjects, or someone else’s hand performing the same movement as the subject’s hand, indicating an insensitivity to distorted visual feedback.

6.1.3 Intentional binding in schizophrenia

One important phenomenon that links time perception with agency is intentional binding, the subjective contraction of time between a voluntary action and its sensory consequence (Haggard et al., 2002). This contraction of time occurs only after self-produced actions and after actions caused by external agents (Engbert et al., 2008) and so is specific for internal motor representations of self-produced actions. It was proposed that, by reducing the perceived time between an action and its consequence, intentional binding allows more accurate prediction of the outcomes of actions and subsequently better agency discrimination (Eagleman & Holcombe, 2002; Wenke & Haggard, 2009). Importantly, it has been demonstrated that the presence of intentional binding occurs when there are explicit experiences of agency over the action and its consequences (Ebert & Wegner, 2010). Finally, intentional binding is a measure of the efficacy of motor commands to affect downstream neural processes, particularly timing circuits (Moore et al., 2012; Moore & Obhi, 2012).

There is indirect evidence that the effect of motor commands on timing mechanisms, specifically related to representations of the self, may be impaired in passivity symptoms. Blakemore et al. (2000) found that individuals with passivity symptoms did not produce the expected sensory attenuation of a self-induced tickling sensation relative to passive, externally-generated actions. Such results seem to indicate weakened, not strengthened, efficacy of motor commands on post-action processes in passivity symptoms. However, evidence from three studies of intentional binding in people with schizophrenia, undifferentiated by symptom profile, suggests there is an increase in the efficacy of motor commands, with findings of greater intentional binding in these samples (Franck et al., 2005; Haggard et al., 2003; Voss et al., 2010).
One limitation of the above three studies is their use of only two conditions (active/intentional and passive actions), which both represent the participants' own actions, and not the representations of actions of others. This is important for two reasons. First, our previous study showed that this is a fundamental distinction because differences exist between self- and other-representations in people with passivity symptoms (K. T. Graham et al., 2014). That is, performance on the rubber hand illusion found changes in representations of the bodily self (increases in feelings of disembodiment and loss of agency over their actual hand) and not to mental representations of external body parts (K. T. Graham et al., 2014). Therefore, a closer investigation of this distinction is warranted. Second, given many people with schizophrenia have difficulties with agency attribution in general (Daprati et al., 1997; Jeannerod, 2009; Kircher & Leube, 2003; Synofzik & Voss, 2010), inclusion of a condition whereby participants observe movements of another agent (‘Other’ condition) can provide insight into whether issues with intentional binding contribute to these agency disturbances specifically through processes triggered by efferent signals or if there are more general agency attribution deficits. Additionally, the studies of intentional binding only used one interval (250 ms), despite evidence from some studies that intentional binding decreases with increasing interval length (Ebert & Wegner, 2010; Haggard et al., 2002).

6.1.4 Aims and hypotheses

The aim of the current study was to assess the modulation of time perception by voluntary actions in people with passivity symptoms. This was achieved using an interval estimation procedure, in which participants estimated the interval between an action and consequence across three movement conditions (voluntary movements by the participant, passive movements of the participant induced by the experimenter and observed movements of another agent) at three intervals (200, 400 and 600 ms), in people with schizophrenia, with and without passivity symptoms, and healthy controls. A secondary aim was to assess the relationship of working memory to time perception in people with schizophrenia. This study is novel as it looked specifically at passivity symptoms in schizophrenia, investigated intentional binding across three intervals and used an “Other” movement condition.

We hypothesised that (i) both clinical subgroups would experience a reduction of perceived time across all conditions, (ii) people with passivity symptoms would show no difference in interval time estimation between the three movement conditions, (iii)
that the clinical group without passivity symptoms would report shorter perception of intervals after active movements; and (iv) the changes of time perception in hypothesis (i) would be correlated with performance on a working memory task.

6.2 Methods

6.2.1 Participants

Community individuals (24 males and 24 females) took part in this study, of which 43 completed testing and were included in the analysis (see Table 6.1 for demographics). Participants were recruited through community advertising. Exclusion criteria for all participants included organic brain disease, substance-use disorder or a diagnosis of a schizophrenia-spectrum disorder or psychosis. Participants were screened for all major psychiatric disorders using the Mini-International Neuropsychiatric Interview (MINI). The sample of people with schizophrenia (n = 39) was recruited from the research database of the WA Family Study of Schizophrenia (Hallmayer et al., 2003; Jablensky, 2004). All individuals met both International Classification of Diseases (ICD-10) and Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) criteria for a lifetime diagnosis of schizophrenia or schizophrenia-spectrum disorder, and were community outpatients stabilized on medication. Exclusion criteria included comorbid organic brain disease or substance-use disorder that could account for the psychotic symptoms, or language difficulties.

The study protocol was explained to all participants and written consent was obtained. Participants were reimbursed $30 for their time. All study protocols conformed to the guidelines of, and were approved by, the North Metropolitan Mental Health Service Human Research Ethics Committee.

6.2.2 Clinical evaluation

Clinical evaluation was conducted with the Scales for the Assessment of Positive and Negative Symptoms (SAPS and SANS; Andreasen, 1984a, 1984b). Passivity symptoms were assessed using the Passivity Symptoms Interview (PSI; Waters et al., 2009) with selected items from the Schedules for Clinical Assessment in Neuropsychiatry (SCAN, Version 2.1; items: 17.008, 18.005-18.010, 18.012-18.017, see Wing et al., 1990). All symptoms were rated in accordance with stringent definitions and assessed for lifetime history and presence in the last 4 weeks as determined by assessment during clinical interview and case-note reviews. Patients were rated as having current passivity symptoms (Pass. +) if they reported two or more
such symptoms in the past 4 weeks (n = 15). Patients were rated as ‘Pass. -’ (n = 24) if
they had a positive rating of at least two passivity symptoms in the past, but not within
the past four weeks OR had never experienced these symptoms during any period.
Independent classification of patients into groups was conducted by two of the
investigators (KG and FW).

Table 6.1. Demographic and neuropsychological information of participants

<table>
<thead>
<tr>
<th></th>
<th>Controls (n = 43)</th>
<th>Pass. - (n = 24)</th>
<th>Pass. + (n = 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (M/F) a</td>
<td>23/20</td>
<td>18/6</td>
<td>8/7</td>
</tr>
<tr>
<td>Age (years) b</td>
<td>44.6 ± 1.7</td>
<td>43.1 ± 1.8</td>
<td>42.8 ± 2.5</td>
</tr>
<tr>
<td>Years Education b</td>
<td>13.8 ± 0.3</td>
<td>12.8 ± 0.4</td>
<td>14.2 ± 0.6</td>
</tr>
<tr>
<td>WTAR b</td>
<td>104 ± 2.0</td>
<td>98.4 ± 3.9</td>
<td>98.9 ± 3.1</td>
</tr>
<tr>
<td>Trail Making Test A b</td>
<td>30.7 ± 1.9</td>
<td>52.5 ± 3.6 ***</td>
<td>42.7 ± 3.4 *</td>
</tr>
<tr>
<td>SAPS Composite b</td>
<td>-</td>
<td>15.2 ± 2.2 ^^^</td>
<td>28.2 ± 3.7</td>
</tr>
<tr>
<td>SANS Composite b</td>
<td>-</td>
<td>28.3 ± 3.4</td>
<td>24.8 ± 2.7</td>
</tr>
<tr>
<td>Chlorpromazine equivalents</td>
<td>-</td>
<td>756 ± 115</td>
<td>680 ± 114</td>
</tr>
</tbody>
</table>

Mean ± SEM of selected covariates. a Fisher’s Exact Test. b One-way ANOVA with Tukey’s HSD post-hoc comparisons (Bonferroni corrected).
Different from controls: * p<0.05, ** p<0.01, *** p<0.001
Different from Pass. +: ^ p<0.05, ^^ p<0.01, ^^^ p<0.001
Antipsychotic doses converted into chlorpromazine equivalents using the formulae given in Woods (2003), Maudsley Prescribing Guidlines (D. Taylor et al., 2009) and Psychotropic Drug Guide (Bazire, 2009).

6.2.3 Materials & Procedures

A questionnaire assessing age, sex, years of education and self-reported medical problems was administered to all participants. All participants were administered a measure of verbal working memory, the backwards digit span, (Lezak et al., 1995), before the interval estimation procedure. For this task, the examiner verbally presented a string of digits at a rate of one per second. The participant then repeated the digits back to the examiner in reverse order. The string of digits increased by one until the
participant failed to correctly repeat the order on two consecutive strings of the same length.

The interval estimation procedure (adapted from Engbert et al., 2008) was delivered on the software EPrime (v 1.2). The participant was asked to judge the duration of time between an action (a button press on a computer keyboard) and a subsequent stimulus (a 100 ms, 1 kHz tone played through headphones).

There were three movement conditions: in the Active condition, the participant rested their finger in a brace on the spacebar and intentionally pushed the spacebar. In the Passive condition, the participant had their finger attached to the brace connected to the spacebar. A wire was connected to the brace from beneath the keyboard and was used to depress the spacebar when necessary (entirely controlled by the experimenter and not visible to the participant). In the Other condition, the experimenter rested their hand on the spacebar and pushed the spacebar; participants were instructed to focus on the experimenter’s hand throughout the duration of the block. Each participant took part in all three movement conditions; the order of presentation of the conditions was counter-balanced across participants. Participants were assigned a presentation order in a pseudorandom manner.

Before each movement condition, participants were told to report their answer in milliseconds and that every trial would be less than 1 second and greater than 0 s. They were reminded that 1 s = 1000 ms, 0.5 s = 500 ms etc., and that any answer between 1 and 999 was acceptable. Before each condition, the participant was also instructed to ensure they were looking at the spacebar and their (or the experimenter's) finger on every trial. Each movement condition was presented in a single block and consisted of 45 trials. The interval between the button press and the onset of the tone was 200, 400 or 600 ms. Thus, each interval was presented 15 times per block. Trials began with a 2 cm black cross in the middle of a white background on a computer monitor. When the participant was ready, they pressed the spacebar on the keyboard. The cross immediately disappeared and was followed by a blank screen for the duration of the interval. One second after the interval, a message appeared on the screen asking the participant to “Estimate the time, in milliseconds, the tone was delayed after you pressed the spacebar”. The participant gave an unspeeded verbal response, which was entered into the computer by the experimenter. A blank white screen then appeared for 1000 ms before the cross reappeared and the next trial began. No practice trials or reference times were given as we were interested in biases between movement conditions and not accuracy of the estimations.
6.3 Results

6.3.1 Statistical methods

All statistical analyses and figures were completed using the statistical software R (version 3.0.1; R Core Team, 2012), and the packages ‘nlme’ (Pinheiro et al., 2013) and ‘car’ (Fox & Weisberg, 2011). Analyses were performed using linear mixed-effects models with perceived interval as the dependent variable and movement condition (Active, Passive or Other), interval (200, 400 or 600 ms) and group (Controls, Pass. – or Pass. +) as the fixed effects. The random effects term had random participant effects with a nested movement condition by interval interaction. Analysis of deviance (ANODEV) was performed on the terms of the model. Where the ANODEV model revealed significant main effects, linear treatment contrasts were performed. Where Analysis of Deviance (ANODEV) on the terms of the model revealed significant interaction terms, interaction contrasts comparing difference scores on each of the levels of the factor were performed. i.e. [Controls (Passive) – Controls (Active)] - [Pass. + (Passive) – Pass. + (Active)]. Alpha was set at 0.05.

6.3.2 Passivity symptoms: Intentional binding at 200, 400 and 600 ms

The ANODEV revealed no main effect of group ($F(2, 79) = 2.13, p = 0.34$) but there was a main effect of movement condition ($F(1, 635) = 1.1, p = 0.004$), with the Passive condition being perceived as shorter than Other and Active conditions, and a main effect of interval ($F(1, 635) = 502, p < 0.0001$), with participants reporting an increase in the perceived interval with longer intervals.

The group by interval interaction was also significant ($F(2, 635) = 23.1, p < 0.0001$). This interaction can be seen in Figure 6.1. The slopes (± standard error) were Controls, slope = 0.64 ± 0.06, Pass. –, slope = 0.50 ± 0.08 and Pass. +, slope = 0.39 ± 0.10. Interaction contrasts revealed that the slope of the increase in perceived interval across the intervals was significantly different between Controls and Pass. + (slope $p = 0.05$), Controls and Pass. – ($p = 0.008$) but not between Pass. + and Pass. – ($p = 0.76$). These results demonstrate that as the interval increases, people with schizophrenia, regardless of passivity symptom profile, perceive the interval to be shorter compared to controls.

The group by condition interaction neared, but did not reach, significance ($F(4, 635) = 2.18, p = 0.07$). Given the $p$-value and our a priori hypothesis that there would
be changes in intentional binding in both groups of people with schizophrenia, it was decided to run interaction contrasts. The interaction can be seen in Figure 6.2.

For Controls, the perceived interval was significantly longer in the Active condition compared to the Other condition ($p = 0.04$), and neared, but did not reach, significance for the Active and Passive conditions contrast ($p = 0.06$). The perceived interval was not significantly different between Passive and Other conditions ($p = 0.87$). This pattern of results, where intervals after active movements are perceived as longer compared to passive movements, is a phenomenon termed perceptual repulsion and has previously been demonstrated to be related to the age of the participants (K. T. Graham, Martin-Iverson, & Waters, 2015; see discussion below). For Pass. -, the perceived interval was significantly longer for the Active condition compared to the Passive condition ($p = 0.002$) and significantly longer in the Other, compared to Passive, condition ($p = 0.003$), but there was no significant difference between the Active and Other conditions ($p = 0.98$). Finally, none of the interaction contrasts were significant.

Figure 6.1. Changing perception of a delay between an action and a tone in people with passivity symptoms. Participants estimated the time between an action (a button push) and a tone, with a 200, 400 or 600 ms delay between action and tone; movements were performed across three movement conditions; data are shown here collapsed across movement condition. Participants were healthy controls (Controls), people without a current experience of passivity symptoms (Pass. -), people with a current experience of passivity symptoms (Pass. +). Data given are mean ± SEM. Contrasts for post-hoc comparisons are reported in text.
for Pass. + (all $p > 0.05$). The three-way interaction between group, movement condition and interval was not significant ($F(4, 635) = 1.42, p = 0.84$).

As we were specifically interested in the perception of time in the Pass. + group, we conducted treatment contrasts on the perceived interval, comparing Active to Passive, Active to Other and Passive to Other conditions for each of the 200, 400 and 600 ms intervals. None of these contrasts were significant (all $p > 0.05$). From this, people with passivity symptoms did not perceive a difference in the interval between Active, Passive or Other conditions at any of the intervals presented and so did not display modulation of time perception by voluntary movements.

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Figure 6.2. Modulation of time perception by active movements in people with passivity symptoms. Participants estimated the time between an action (a button push) and a tone (delays were 200, 400 or 600 ms; data shown are collapsed across delays), when the participant pushed a button willingly (Active condition; light grey shading), when the participant’s finger was moved for them (Passive condition; white shading) and while watching the experimenter pushing the button (Other condition; dark grey shading). The delay between the action and tone was 200, 400 or 600 ms; data shown are collapsed across the delays. Participants were healthy controls (Controls), people without a current experience of passivity symptoms (Pass. -) and people with current experience of passivity symptoms (Pass. +) Data given are mean ± SEM. ^ 0.05 < $p < 0.1$, * $p < 0.05$. 

As we were specifically interested in the perception of time in the Pass. + group, we conducted treatment contrasts on the perceived interval, comparing Active to Passive, Active to Other and Passive to Other conditions for each of the 200, 400 and 600 ms intervals. None of these contrasts were significant (all $p > 0.05$). From this, people with passivity symptoms did not perceive a difference in the interval between Active, Passive or Other conditions at any of the intervals presented and so did not display modulation of time perception by voluntary movements.
6.3.3 Relationship of working-memory to time perception

Given the group by interval interaction found in the previous section indicated similar slopes between the people with schizophrenia, with and without passivity symptoms, and the previous findings of working memory deficits associated with changes in temporal processing in schizophrenia, we further investigated the role of working memory on time perception in the current sample. Firstly, an independent two sample t-test demonstrated that the mean backwards digit span score (± SEM) was lower in people with schizophrenia (mean = 6.54 ± 0.32) compared to controls (mean = 7.49 ± 0.37); \( t(80) = 1.93, p = 0.03 \). Secondly, an ANOVA was conducted on the patient data, collapsed across movement conditions and the two patient groups, with interval and backwards digit span score included as fixed effects. The ANODEV revealed no significant main effect of backwards digit span score (\( F(1, 37) = 0.18, p = 0.67 \)) but a significant main effect of interval (\( F(1, 74) = 80.3, p < 0.0001 \)). The interval by backwards digit span interaction was also significant (\( F(1, 74) = 10.2, p = 0.006 \)). As can be seen in Figure 6.3, as the interval increased to 400 and 600 ms, higher backwards people with higher digit span scores reported a steady increase in the perceived interval. In contrast, people with lower digit span scores reported a more moderate increase in the perceived interval.

6.4 Discussion

The aim of the current study was to assess time perception after three types of actions (active, passive, other) in people with and without passivity symptoms of schizophrenia, and in healthy controls. In line with our hypothesis, people with passivity symptoms showed no differences in interval estimations across the three movements, and the interval estimations of those without passivity symptoms were longer after active and other movements, compared to passive movements. We also found a reduction in the slope of the perception of time with increased interval in people with schizophrenia, relative to controls. There was also an association of working memory with time perception in people with schizophrenia. These findings will now be discussed in turn.

6.4.1 Estimation of intervals in healthy controls
Controls reported the interval between a button press and a subsequent tone to be longer in the Active condition compared to the Passive and Other conditions. Previous findings using similar tasks have found that intervals after voluntary movements are perceived to be shorter than for passive movements in young undergraduate samples (Ebert & Wegner, 2010; Engbert et al., 2008; Haggard, Newman, & Magno, 1999; Wegner & Wheatley, 1999). However, we demonstrated previously that this selective focus on university students masks an age effect. Increased age has an effect on timing mechanisms relating to active and passive movements such that healthy older individuals do not display this pattern of perceiving an interval to be shorter after active, relative to passive, movements. Rather, ‘perceptual repulsion’ is present, whereby intervals after active movements are perceived to be longer than after passive movements (K. T. Graham, Martin-Iverson, & Waters, 2015). We hypothesised that this may be due to a contraction of the size of the temporal window of associability.

![Figure 6.3](image.png)

**Figure 6.3.** Effect of a measure of working memory (backwards digit span) on time perception in a group of people with schizophrenia (n = 39). Participants estimated the time between an action (a button push) and a tone, with a 200, 400 or 600 ms delay between action and tone; movements were performed across three movement conditions; data are shown here collapsed across movement condition. To aid in data presentation, subjects were binned into three groups: 5 ≤ (“Low”, n = 13), 5 < BDS < 8 (“Middle”, n = 17), ≥ 8 (“High”, n = 9). Data shown are mean ± SEM.
specific to actions as a consequence of developmental changes and sensorimotor learning associated with ageing. The current study also demonstrates that the increase in the estimated interval was specific to the Active condition i.e. not present after induced movements or observations of an external agent. This confirms that, as intentional binding is a product of voluntary actions in younger adults, perceptual repulsion is initiated by voluntary actions in older adults.

6.4.2 Reduction in the estimation of intervals by people with schizophrenia

The current study found a significant decrease in the slope (i.e. a flatter slope) of the perceived interval over 200 – 600 ms in people with schizophrenia, who perceived the longer intervals to be shorter in comparison to healthy controls. This decrease in the perception of the length of an interval in people with schizophrenia is a consistent finding in the literature and has been interpreted as being the consequence of a reduction in the rate of an internal pacemaker (Carroll et al., 2008; Elvevåg et al., 2004; Elvevåg et al., 2003; K.-H. Lee et al., 2009; B. Martin et al., 2013; Papageorgiou et al., 2013; Rammsayer, 1990; Waters & Jablensky, 2009). This change in the perceived interval was not associated with chlorpromazine equivalents in the current study.

6.4.3 The role of dopamine in psychosis-like experiences (PLE), schizophrenia and time perception

These findings in people with schizophrenia detailed above lead to an apparent contradiction. In a previous study (K. T. Graham, Martin-Iverson, & Waters, 2015), we found that PLE, phenomena that are phenomenologically similar to the positive symptoms of schizophrenia but are present in healthy controls and are not severe enough to constitute a diagnosis of psychosis (Hanssen et al., 2003; Kendler et al., 1996; Meehl, 1962; Venables et al., 1990), were associated with an increase in the perceived interval between an action and a tone (unlike the current findings that showed an overall decrease in perceived interval). Given the strong evidence linking dopamine to schizophrenia (see Howes & Kapur, 2009 for a review), the raised pre-synaptic levels, release and synaptic concentrations of dopamine in people with PLE (K. C. Chen et al., 2012; Howes et al., 2013; Taurisano et al., 2014; Woodward et al., 2011) and the strong evidence linking dopamine to regulation of internal timing mechanisms under 1 second (Rammsayer, 1993, 1999, 2009), we proposed that this effect was due to increased dopamine levels in people with PLE causing an increase in the speed of the internal clock.
The contradiction is then: given that the level of dopamine transmission in PLE is intermediate between healthy controls and schizophrenia, it would then be expected that people with schizophrenia would also have a faster pacemaker. One explanation for this disparity may be the chronic administration of antipsychotic medication to people with schizophrenia. All current antipsychotic medications are competitive antagonists or partial agonists of the dopamine D₂ receptor (Horacek et al., 2006; Seeman, 2006; Seeman & Lee, 1975; Seeman et al., 1976) and antagonism of the D₂ receptor leads to a decrease in the rate of the internal pacemaker in both animal models (Maricq & Church, 1983; Meck, 1986) and healthy human controls (Rammsayer, 1997, 1999). There is, however, evidence against the timing changes in schizophrenia being solely a side-effect of antipsychotic administration. Investigations, including the current study, have not found a relationship between the level of antipsychotic medication and the perceived length of the interval (Carroll et al., 2008; K.-H. Lee et al., 2009), as would be expected if dopamine-blockade were responsible for the changes seen in time perception.

6.4.4 The role of working memory in time perception

Another explanation links working memory and time perception, specifically, poorer working memory is associated with a decrease in time perception (K.-H. Lee et al., 2009; Roy et al., 2012). The relationship of working memory to time perception is described in the predominant model of temporal processing, an information-processing version of scalar timing theory (Gibbon, 1977, 1991; Meck, 1996). This framework dissociates pacemaker, memory/accumulator and decisional/comparator stages of temporal processing. Of importance for this study, scalar timing theory proposes that an internal pacemaker produces units of time, which are sent to an accumulator, via an attention-gated switch. The units of time are stored, via working memory, in the accumulator and are then accessed by a decision-making unit in order to determine the length of the interval. If working memory deficits of schizophrenia affect the ability of the accumulator to store time units, less time units will be accumulated in a given period and so an interval will be perceived to be shorter. Events then need to occur further apart in time in order to be perceived by people with schizophrenia as occurring one after another, rather than simultaneously (Foucher, Lacambre, Pham, Giersch, & Elliott, 2007; Giersch et al., 2009). Dysfunctions in the accumulator stage are not necessarily incompatible with changes in the rate of an internal pacemaker as other studies have isolated changes in clock speed (Elvevåg et al., 2003; Rammsayer, 1990). What the current study indicates is that subjective time perception and explicit interval
judgements are dominated by changes in the accumulator, not internal pacemaker changes, in schizophrenia.

6.4.5 Specificity of time perception changes to passivity symptoms

The finding that both the Pass. – and Pass. + groups had a significantly smaller slope than controls did not support our hypothesis that there would be more severe changes in time perception in people with passivity symptoms, as has been found previously (Waters & Jablensky, 2009). There is a possibility that people with passivity symptoms did report an overall lower interval as both the mean perceived interval, collapsed across movement condition and interval, (mean ± SD: Controls = 256 ± 236 ms, Pass. – = 307 ± 277 ms, Pass. + = 221 ± 227 ms) and the slope (mean ± standard error: Controls = 0.64 ± 0.06, Pass. – = 0.50 ± 0.08 and Pass. + = 0.39 ± 0.10) were lowest in the Pass. + group. However, these differences were not significant in the ANODEV. Given the large standard deviations and the smaller sample size of the Pass. +, it is likely to be an issue of statistical power or methodology.

6.4.6 Role of intention in time perception in people without passivity symptoms

While the perceived intervals were similar after Passive and Other movements (but longer for Active movements) in healthy controls, individuals without passivity symptoms reported the interval to be the same after voluntary movements and observed movements of others. Although this was unexpected, we believe it may be consistent with a group of symptoms known as experiences of activity (or delusions of influence). These are the phenomenological opposite of passivity symptoms whereby people with these symptoms feel that they are in control of the thoughts and actions of other people and/or can control external events in the environment that they couldn’t feasibly influence (J. R. Martin, 2013; Stanghellini & Rossi Monti, 1993). For example, a person may believe they are controlling the words that another person speaks or that they are controlling the events that they see on TV. In these experiences, the person erroneously attributes self-agency over external events. In support, hyper-attribution of agency to the self (or self-biases, as opposed to external-biases) is a consistent finding in people with schizophrenia (undifferentiated by symptom profile) on agency tasks requiring self or other judgements (Daprati et al., 1997; Fourneret et al., 2001; Franck et al., 2001). The current study demonstrates that the perception of time after observing movements of others results in a similar pattern of behaviour seen after voluntary movements in people with schizophrenia. The possibility therefore exists that people with schizophrenia
(without passivity symptoms) perceive consequences of other people’s actions as if they were performing them themselves, leading to erroneous (internal) agency attribution. This is the opposite pattern to people with passivity symptoms, who have make erroneous agency judgements, but attribute that agency to external sources. Additionally, given the relationship of age to intentional binding described previously, the presence of perceptual repulsion in people without passivity symptoms may be linked to the older mean age of the participants of the current study (mean = 44.6), compared to previous studies of intentional binding that have found exaggerated binding in people with schizophrenia (Franck et al., 2005, mean = 33; Haggard et al., 2003, mean = 44.6; Voss et al., 2010, mean = 34.8).

6.4.7 Role of intention in time perception in people with passivity symptoms

The Pass. + group showed no difference in perceived interval between the three movement conditions, in contrast to both controls and Pass -. It is not clear if this result is due to changes linked to the Passive or Other movement conditions or an absence of time modulation triggered by intentional processes in the Active condition. It is known that intentional binding is initiated by voluntary movements, but not by passive induced movements or observation of others’ movements, in young healthy adults (Engbert et al., 2008; Haggard et al., 2002). It has also been proposed that intentional binding is initiated by efferent signals of dedicated predictive motor processes that ‘anticipate’ the sensory consequences of an action (Haggard & Clark, 2003). The specificity of intentional binding to voluntary movements strongly implies the contribution of predictive processes. It is also known that interference of the pre-supplementary motor area (SMA) with repetitive transcranial magnetic stimulation (rTMS), inhibits intentional binding in healthy controls (Moore, Ruge, et al., 2010). This is important as the pre-SMA is a region strongly implicated in the preparation and initiation of actions (Fried et al., 1991; Picard & Strick, 2001) and a likely source of the efferent signals that initiate modulation of time perception. From these lines of evidence, it is reasonable to presume that the current results in the Pass. + group are a result of efferent commands failing to induce the same post-action processes (modulation of time perception and sensory attenuation) as they do in healthy controls.

6.4.8 Functional significance of findings in passivity symptoms

Speculatively, the lack of modulation of time perception by intentional actions in passivity symptoms may be a result of imprecise motor anticipatory processes that do
not accurately predict the outcomes of voluntary movements and hence modulate the appropriate post-action processes, a finding that has been observed in people with schizophrenia previously (Shergill et al., 2005; Voss et al., 2010) and in passivity symptoms specifically (Blakemore, Smith, et al., 2000; Lindner et al., 2005; Synofzik et al., 2010). This means that people with passivity symptoms fail to discriminate between internally-generated and externally-generated events because the underlying neural mechanisms do not operate differently in these two different types of movements. That the underlying internal timing mechanisms are the same for active, passive or observed movements may explain why these people have difficulties differentiating self-initiated actions from that of others, supporting previous findings of self-agency in this group.

This finding complements an accumulating body of evidence of multiple body representation alterations in people with passivity symptoms, including body schema and body image alterations (K. T. Graham et al., 2014). Altogether, the impaired prediction of actions in passivity symptoms may be the result of a combination of processes, including synchronicity (timing) and coordination of body representations and/or distorted information from these representations. This is further supported by previous findings that the severity of passivity symptoms is positively correlated to the degree of imprecision in motor predictions (Synofzik et al., 2010).

Two further steps are then required for the onset and maintenance of passivity symptoms. One is that compromised action prediction might result in confusion regarding whether actions have been generated by the self, perhaps leading to an over-reliance on external agency cues (J. R. Martin, 2013; Moore & Fletcher, 2012; Moore & Obhi, 2012; Voss et al., 2010). When combined with a diminished sense of self (from alterations of body schema and body image), impaired construction of the chronological order of efferent and afferent sensations - particularly for events of longer durations that are not normally associated with voluntary movements - people with passivity symptoms may incorrectly perceive external events as being closely related to internal events and so the source of agency is replaced by that of an external agent.

6.4.9 Limitations

One limitation is the relatively smaller size of the Pass. + group compared to the Pass. – and Control groups; unfortunately the group sizes were restricted by our approved recruitment process. Another limitation is that we have demonstrated previously that there is an effect of age on the modulation of time perception by active movements, such that increasing age is associated with a dilation in the perceived time
between an action and a tone, instead of a contraction of perceived time as is found in younger samples, in a sample of 43 healthy controls (K. T. Graham, Martin-Iverson, & Waters, 2015). Given the smaller sample sizes of the two schizophrenia groups, there was not a large enough age range of younger participants in these groups to be able to conduct an analysis that included age as a fixed effect.

6.4.10 Conclusions

This study investigated intentional binding in people with schizophrenia (with and without passivity symptoms), using an interval estimation procedure (200, 400 and 600 ms intervals) between a button press and a tone with voluntary actions, passive actions and observed actions of an external agent. In line with previous findings, people with schizophrenia had a significantly flatter slope of the estimated interval with increasing interval length. For the first time, it was demonstrated in the study that i) people without passivity symptoms experienced the interval to be the same after voluntary actions and observed actions of others and ii) people with passivity symptoms do not display any modulation of time perception by actions, indicating a deficit in predictive motor commands to affect post-action processes. The overall reduction in the perception of interval length and the changes in action-modulation of time perception may then lead to people with schizophrenia (without passivity symptoms) to over-attribute self-agency and people with passivity to misattribute agency to external sources.

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Chapter 7 – General Discussion

7.1 Summary of aims

The main objective of this thesis was to assess the hypothesis that body representation alterations underlie passivity symptoms by conducting an assessment of body representations in a sample of people of schizophrenia, divided into groups based on their lifetime history of passivity symptoms. Two samples were used in this thesis: healthy controls from the community and a sample of individuals (outpatients) with schizophrenia.

The specific aims of the thesis were to: validate existing tools that assess body representations in a sample of healthy controls recruited from the broader community, determine the association of body representations with selected variables such as psychosis-like experiences (PLE), and assess multiple body representations (body schema, body image, body structural description and body agency) in people with and without passivity symptoms.

Throughout, evidence was sought for a conceptual framework that proposes that there is a continuum of alterations in body representations across the entire schizophrenia spectrum, ranging from slight deviations in healthy people with PLE, to major body representation abnormalities in people with schizophrenia, with a trait-like vulnerability conferring more pronounced abnormalities in people with a past history of passivity symptoms and the most prominent alterations in people currently experiencing passivity symptoms.

7.2 Summary of findings

In chapter two, a principal components analysis was conducted on the questionnaire data for the projected hand illusion (PHI) in healthy controls (n = 48) which partially validated prior findings, and from which four components were extracted: “Embodiment of ‘Other’ Hand”, “Disembodiment of Own Hand”, “Agency” and “Deafference”, in both synchronous and asynchronous conditions of the PHI. Decreased age and increased score on the PLE questionnaire were associated with stronger endorsement of items assessing the illusion. This indicates there are changes in body agency and body image in younger community individuals and those who have higher levels of PLE.

In chapter three, performance on the hand laterality task (HLT) revealed that schizophrenia individuals with passivity symptoms (both current and past history) had
greater alterations of body schema (greater number of errors and slower response time) relative to people without passivity symptoms and healthy controls. During the PHI, people with a past or current history of passivity symptoms also had greater experiences of disembodiment of their own hand, indicative of body image changes. A reduced sense of agency over one’s own hand (induced by the PHI) was a common feature of all clinical subgroups. Finally, people with current passivity symptoms did not report the usual reduction of the illusion with a 500 ms delay in visual feedback during the PHI (asynchronous condition), suggesting a role for internal timing problems in body representation abnormalities in schizophrenia.

In chapter four, there was no difference between the clinical subgroups in performance on tasks assessing body structural description; people with schizophrenia displayed more errors on the in-between task (IBT), but not on the matching body parts by location task (MBPBL), compared to controls. By contrast, the body distortion questionnaire revealed body image alterations that were dependent on symptom profile. People with a current experience of passivity symptoms reported more experiences of depersonalisation and unusually large and unusually small body parts, while people with any history of passivity symptoms (current or past) reported higher experiences of boundary loss than people without passivity symptoms and healthy controls.

In chapter five, investigation of the intentional binding task (interval estimation procedure) in healthy controls demonstrated that intentional binding was present in healthy younger adults, but gradually lessened with age until older adults displayed a phenomenon referred to as ‘perceptual repulsion’, where they reported intervals to be longer after active movements compared to passive movements. Independent of age, increasing PLE scores were associated with increased intentional binding.

In chapter six, an investigation of the sense of agency and time perception with the intentional binding task in people with schizophrenia again suggested changes in internal timing mechanisms. The results found a shallow slope of time perception with increasing interval length in people with schizophrenia, indicating that they perceived intervals to be shorter than they actually were, particularly at longer intervals. The perception of the time interval by people with passivity symptoms was not modulated by actions, i.e. the length of the interval was perceived to be the same after active, passive or observed movements. By contrast, people without passivity symptoms perceived the interval after active movements and observed movements to be longer than intervals after passive movements.

These findings, in relation to the thesis aims, will now be discussed.
7.3 Body representations in a community sample of healthy controls

Almost all studies investigating body representations in the community have been performed in university undergraduate samples. Since these groups are different in demographic profile from clinical samples typically used in research and in this thesis, this thesis aimed to investigate two body representations tasks in a sample of healthy controls who were broadly similar in characteristics to community adults with regards to age, levels of education and gender. Two tasks were investigated: the PHI (assessing body schema with proprioceptive drift, and body image and body agency with questionnaire scores) and an interval estimation procedure to assess intentional binding (body agency).

7.3.1 Projected hand illusion (PHI)

Overall, a psychometric analysis of the questionnaire assessing the PHI extracted similar components to a previous psychometric study of the rubber hand illusion in undergraduate students (Longo et al., 2008). This concordance provides validation of assessment of the subjective experience of the PHI as a tool to assess body image and body agency. Consequently, this task was used in chapter three to assess these two body representations in people with schizophrenia.

More specifically, psychometric analysis of a questionnaire assessing the PHI in chapter two found that experience of the illusion was dissociable into four components in healthy controls: Embodiment of the Other Hand (“Embodiment”), Disembodiment of the Own Hand (“Disembodiment”), Agency and Deafference. As with the rubber hand illusion, the Embodiment component indicates that the PHI also induces an illusory sensation of embodiment of an external object (the subjective sensation that the hand on the screen is in fact the participant’s hand). As a body part must be incorporated into the body image for it to be embodied (Longo et al., 2009; Tsakiris & Haggard, 2005), the PHI is a legitimate tool for the assessment of body image. The Disembodiment component corresponds closely to the ‘Loss of Ownership’ component previously reported by Longo et al. (2008). It has been proposed that embodiment of the other hand is achieved by suppression of embodiment of the participant’s own hand (Albrecht et al., 2011; Longo et al., 2008) leading to the experiences of disembodiment during the illusion. Thus, assessment of both embodiment and disembodiment during the illusion allows an in-depth investigation of body image. Finally, the Agency component indicates that it is possible to experience a sense of agency over the ‘other’
hand (e.g. the image) during the PHI. Overall, the presence of these four components indicate that the PHI permits the assessment of multisensory integration processes underlying two body representations, body image and body agency.

In contrast to the findings of the previous paragraph, proprioceptive drift during the PHI was not found to be a reliable measure of body schema. Proprioceptive drift is the shift in the perceived location of the own hand towards the other hand after synchronous stroking and is reported to be a measure of body schema (Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005). Chapter two showed that proprioceptive drift was not significantly different between synchronous and asynchronous stroking conditions, and, critically, increased with age. We proposed that these results may be a result of the reduction in proprioceptive acuity with increasing age (Adamo et al., 2009; Goble et al., 2009; Kalisch, Kattenstroth, Kowalewski, Tegenthoff, & Dinse, 2012) and a subsequent increased reliance on visual cues (thus not derived from the body schema) for spatial judgements. Another important finding was the dissociation of the effect of age on proprioceptive drift and on the subjective experience of the illusion (see section 7.3.4 below). This distinction is important as some studies of hand illusions have treated proprioceptive drift as a more objective but indirect measure of embodiment of the other hand (Costantini & Haggard, 2007; Tsakiris, Costantini, & Haggard, 2008; Tsakiris & Haggard, 2005; Tsakiris, Hesse, Boy, Haggard, & Fink, 2007; Tsakiris et al., 2006). This thesis, in accordance with previous studies (Holle et al., 2011; Kammers, Longo, et al., 2009; Rohde et al., 2011), provides further evidence that proprioceptive drift and embodiment are not the same phenomena. In summary, this thesis found evidence that proprioceptive drift is not a reliable measure of body schema in community controls nor should it be used as a substitute measure for embodiment during the PHI. As a consequence of this finding, proprioceptive drift was not assessed in chapter three.

7.3.2 Intentional binding (Interval estimation procedure)

The second task to be investigated in the sample of community controls was the interval estimation procedure with active and passive movements of the participant’s hand (Chapter 5). This task is used to assess changes in time perception linked to voluntary actions (intentional binding) as a proxy measure of body agency (Haggard et al., 2002; Moore & Obhi, 2012). The main finding from chapter five was that the effect of voluntary actions on time perception was age dependent. In contrast to previous findings using both the Libet clock method (Haggard et al., 2002; Moore & Haggard, 2008; Tsakiris & Haggard, 2003) and the interval estimation procedure (Cravo et al.,
2009; Ebert & Wegner, 2010; Engbert et al., 2008; Moore, Wegner, et al., 2009; Wenke & Haggard, 2009), the broad sample of community controls reported the interval to be shorter after passive, compared to active, movements, a phenomenon termed ‘perceptual repulsion’. Further analysis revealed that, at the 200 ms interval, intentional binding was present in younger adults but gradually lessened with age. With increasing age, participants reported the interval after active movements to be longer than intervals after passive movements. As such, intentional binding does not appear to be generalisable to samples of individuals representative of the broader community, at least in the current sample. This does not necessarily exclude intentional binding as a proxy measure of body agency. Simply, that perceptual repulsion may be present in samples of community adults and results from clinical samples should be interpreted accordingly.

7.3.3 The body representations as separate constructs

There are academic questions whether body representations can be classed as separable constructs, or whether they co-vary (cannot be truly separated). Although this thesis did not directly test the relationship between the four body representations, several lines of indirect evidence were obtained to support that they may be, at least partially, separate constructs. Firstly, in chapter two, the component analysis of the questionnaire data assessing the PHI found that questions detailing experiences of Embodiment (a measure of body image) and Agency (a measure of body agency) loaded onto separate components. This finding is mirrored by previous findings of a double-dissociation of agency and embodiment using a modified version of the rubber hand illusion (Kalckert & Ehrsson, 2012; Tsakiris et al., 2006). As such, this thesis provides psychometric evidence for the distinction between body image and body agency. Another important finding was the dissociation of the effect of age on proprioceptive drift and on embodiment of the other hand (see section 7.3.4 below), in line with previous work finding dissociations of proprioceptive drift and embodiment (Holle et al., 2011; Holmes & Spence, 2007; Kammers, Longo, et al., 2009; Rohde et al., 2011). This differential effect of age is consistent with separate body representations, namely body image and body schema, underlying each of these phenomena. Similarly, that increased age was associated with decreased intentional binding but with increased proprioceptive drift lends support to the separation of body schema and body agency. Finally, as detailed in section 7.3.4 below, the differential performance by each clinical subgroup on each task is also an indicator that these tasks are assessing separate constructs of body representations. This conclusion underscores
previous studies (e.g. Schwoebel & Coslett, 2005) that have found that performance on various tasks purported to assess different body representations (including the hand laterality task and matching body parts by location) loaded onto different components corresponding to body schema, body image and body structural description. While this provides supports for separable body representations, it is questionable whether one representation can exist without another. For example, can a person have intact agency without an intact sense of body ownership? Further studies using neurological populations are a fruitful way to answer some of these questions.

7.3.4 Association of body representations with demographic variables

A secondary aim of the thesis was to examine the relationship of demographic variables to body representations in healthy controls.

In chapter two, it was found that females reported higher levels of embodiment during the illusion than males, replicating the findings of previous studies (Egsgaard et al., 2011; Longo et al., 2008). It was also found in chapter two that the perception of the illusion decreased with age, reflecting results of a previous study that utilised a mirror illusion (Tajadura-Jiménez et al., 2012). This was opposite to the relationship of age with proprioceptive drift; increasing age was associated with increased proprioceptive drift. As detailed previously, chapter five found that increasing age was associated with a decrease in intentional binding and in fact the opposite effect, termed perceptual repulsion, is observed in older adults. These are potentially important findings for the study of body representations as much of the literature consists of studies in young undergraduate samples. Altogether, the findings indicate that it is important for studies of body representations to report the age of the sample and to determine the association of age with performance on tasks assessing body representations if possible. Caution should also be taken if results in university undergraduate samples are to be generalised to the broader community. Finally, the results of this thesis underline the importance of demographically matching control groups for use in clinical studies.

7.3.4 The relationship of body representations with cognition

Other than an association of performance on a verbal working memory task with the perception of the length of an interval in people with schizophrenia (see chapter 6), no evidence was found for an association of performance on tasks of cognitive functioning (Forward and Backwards Digit Span, Trail Making Test Form A, Wechsler Test of Adult Reading) with the body representations assessed in this study. Few
previous studies have assessed cognitive functioning in relation to body representations and those that have, have also found no significant associations (e.g. Holmes et al., 2006). Although it is possible that more generalised neurocognitive functions, such as working memory and attention, support body representations, the absence of such evidence supports the notion that there are dedicated and specialised mental and neural mechanisms associated with the processing of bodily-experience.

7.3.5 The association of PLE and body representations, and the continuum theory of schizophrenia

It is claimed by some that PLE lie on a continuum from experiences that are similar to positive symptoms of psychosis but do not reach clinical significance, through the schizophrenia prodrome, to manifest psychosis (Claridge, 1997; Claridge & Beech, 1995; Kendler & Walsh, 1995; Pogue-Geile, 2001). Similarly, it has been proposed that schizophrenia is fundamentally a disturbance of the self, with self-representation deficits present throughout the schizophrenia-spectrum (Hirjak et al., 2013; Hur et al., 2014; Moe & Docherty, 2014; Nelson et al., 2009; Nelson et al., 2012; Nelson et al., 2014a, 2014b; Nelson et al., 2008). If body representation alterations underlie the self-representation deficits of schizophrenia, body representation alterations resembling those seen in schizophrenia should be present in people with PLE. It was found in this thesis that higher PLE scores were associated with alterations of body image (increased experiences of embodiment and disembodiment during the PHI) and body agency (increased sensations of control over the other hand during the PHI and increased intentional binding at the 200 ms interval of the interval estimation procedure).

In chapter two, increasing PLE score was associated with higher positive responses on all subscales (embodiment, disembodiment, agency and deafference) of the questionnaire assessing the PHI. This finding is in line with previous studies with the rubber hand illusion that have found a similar relationship between PLE and embodiment (Asai et al., 2011; Germaine et al., 2013; Thakkar et al., 2011) and in people with schizophrenia, who report more embodiment and experience the illusion quicker (Peled et al., 2003; Peled et al., 2000; Thakkar et al., 2011). At the 200 ms delay, it was found that increasing PLE score was associated with an increase in intentional binding. This finding is consistent with previous studies using the Libet clock method that have found a greater intentional binding effect in people with schizophrenia undifferentiated by symptom profile (Haggard et al., 2003) and in people in the prodrome of schizophrenia (Hauser, Knoblich, et al., 2011). No association of PLE and
Proprioceptive drift was found in chapter two. This replicates one finding of no association (Germaine et al., 2013) but clashes with another finding of a positive association of PLE and proprioceptive drift (Asai et al., 2011). It has been reported that people with schizophrenia report greater amounts of proprioceptive drift than healthy controls (Thakkar et al., 2011).

In general, the changes in embodiment, and hence body image, and time perception from intentional binding in people with PLE indicate that people with PLE display alterations of body representations similar in character to alterations of body representations seen in people with schizophrenia. As such, supporting evidence was found for the conceptualisation of schizophrenia as a spectrum of self-disturbances, particularly the body representations body image and body agency. As the measure of body schema, proprioceptive drift, assessed in people with PLE is not reliable and the association of PLE with body structural description was not assessed, this thesis did not provide evidence for the alteration of these body representations in PLE.

7.4 Summary of findings on body representations in schizophrenia and passivity symptoms

7.4.1 Body representation alterations are common to schizophrenia

One objective of this thesis was to assess the integrity of body representations in people with schizophrenia, in order to provide empirical evidence for phenomenological conceptualisations of the disorder which states that it rises from deficits in the fundamental sense of self (Bleuler, 1911; Kraepelin, 1913; Parnas, 2000, 2015; Parnas & Sass, 2001; Sass & Parnas, 2003; Schneider, 1946). A growing body of neuropsychological and behavioural evidence supports such alterations of the sense of self in schizophrenia (e.g. Farrer & Franck, 2009; Hur et al., 2014; Kean, 2009; Mishara, 2005; Moe & Docherty, 2014; Postmes et al., 2014; Thakkar et al., 2011). Overall, evidence in this thesis from analyses performed with all individuals with schizophrenia included as a single group (not divided by symptom profile) underscored these findings, and comprehensively characterised the type of body disturbances in schizophrenia using accepted and validated classification of body representations from studies of neurological disorders.

The current findings demonstrated that people with schizophrenia, as a group, had abnormalities of all four body representations. Specifically there were: alterations of body schema (increased number of errors and latency of response on the hand laterality task), body image (increased experiences of loss of physical boundaries of the body,
increased depersonalisation, increased experiences of increased size of body parts and increased experiences of decreased size of body parts), body structural description (increased errors on the in-between task) and body agency (greater loss of agency over the own hand during the projected hand illusion and changes in modulation of intentional binding by actions).

Novel findings from this thesis include the following:
1) First study to show alterations of multiple body representations in the same sample of people with schizophrenia.
2) This is the first demonstration that people with schizophrenia are impaired on a task that assesses body structural description.
3) This thesis provides wide-ranging empirical support for a conceptualisation of schizophrenia that the diminished sense of self in schizophrenia may be fully or partially a consequence of alterations in body representations.

7.4.2 Specificity of body representation alterations to passivity symptoms

The primary aim of this thesis was to assess body representations in people with passivity symptoms. According to the conceptualisation of schizophrenia previously outlined, passivity symptoms represent a particularly elaborated form of self-disturbance (Jansson, 2015) with individuals transitioning between severities of self-disturbance during the course of their illness (Parnas, 2000, 2015; Parnas & Sass, 2001; Sass & Parnas, 2003). Overall, this thesis found evidence for body representation alterations in individuals with and without passivity symptoms, supporting the idea of a continuum of body representation abnormalities according to the presence of passivity symptoms. Furthermore, the findings suggest the existence of divisions within the body representations.

Alterations of body representations were:
- All individuals with schizophrenia (regardless of symptom profile) had abnormal body structural description (either a reduction in acuity or an issue specifically with the representation of the fingers), and prospective body agency on the PHI;
- People with schizophrenia with past and current passivity symptoms had profound alterations in body image disembodiment (of their own hand on the PHI, and loss of bodily boundaries on the body distortion questionnaire) and
body schema (impaired prediction of proprioceptive consequences of an action), suggesting trait-like abnormalities in the passivity cluster.

- People with current passivity symptoms differed from the other subgroups with additional deficits in timing associated with body agency (during the intentional binding task, and asynchronous condition of the PHI), and increased body image embodiment (of ‘other’ hand during the asynchronous condition of the PHI), as well as body image depersonalisation, and body size distortions.

Altogether, while people with passivity symptoms did not have the most severe alterations of all body representations, they showed a distinct profile of performance characterised by the summation of deficits from (i) general deficits in all people with schizophrenia, (ii) underlying trait-like abnormalities (vulnerability) from the passivity grouping, as well as (iii) specific deficits linked to the presence of these symptoms, so that they were the only group with deficits across all four body representations, and the only group where internal timing abnormalities affected body image and body agency. I will now explain how these body representation alterations may explain passivity symptoms.

7.5 A new conceptual framework for passivity symptoms (explanation of findings)

From the pattern of alterations described above, a) a reduction in the acuity of body structural description and b) a reduction in prospective body agency are found regardless of the particular symptoms an individual with schizophrenia has.

An individual with a vulnerability to passivity symptoms at some time in their illness will also display c) a disruption of body image such that they are more prone to disembodiment of their own body parts and d) a subjective loss of the physical boundaries of the body and e) an alteration of body schema whereby there are unable to accurately predict the proprioceptive consequences of one’s actions.

When an individual is in a psychotic state or in a state where they experience passivity symptoms, the existing body image disembodiment (from their vulnerability to these symptoms) will broaden to include (f) body image depersonalisation and body size distortions, (g) excessive embodiment of ‘other’ body parts, and (h) a disruption of the ability to differentiate self from other due to the lack of modulation of time perception by actions. This provides a compelling explanation of passivity symptoms whereby people report that they no longer feel in control of their thoughts and actions, and that these may be controlled or influenced by other agents.
Thus, an individual needs to display all alterations from a) to h) to experience passivity symptoms. If an individual has alterations a) through e), this suggests the individual has had the symptoms in the past and is vulnerable to experiencing these symptoms again (the risk having implications for treatment of these individuals). If an individual only displays alteration a) and b), the risk of this individual developing passivity symptoms is low unless the body alterations c), d) and e) develop.

The current findings are not inconsistent, and in fact complementary, to existing models of passivity symptoms (forward model and cognitive source-monitoring), but also contribute new knowledge to the research of these symptoms. The findings can also explain some discrepancies within the forward model and schizophrenia literature with the differentiation between body representation subtypes. A discussion of the results in relation to previous models of passivity symptoms and other contemporary models of agency will now follow.

7.5.1 Pre-reflective agency, reflective agency and cue integration theory

A recent model of agency in the psychological literature, that integrates several previous models, consists of two major assertions. Firstly, it posits that there are at least two important divisions to body agency: pre-reflective agency (also known as prospective agency) and reflective agency (David, Newen, & Vogeley, 2008; Moore & Fletcher, 2012; Moore et al., 2012; Synofzik et al., 2008). Pre-reflective agency is a basic low-level feeling of being an agent (“I can move that”), is based on multiple basic sensorimotor processes, including the forward model, and contains predictive components involved in the performance of actions. Typically, pre-reflective agency occurs without conscious awareness but is available for awareness if necessary (Gallagher, 2000; Synofzik et al., 2008). Relevant to the current findings is that pre-reflective agency itself is comprised of subcomponents. Reflective agency is a retrospective process that involves an explicit judgement of an event (“I moved that”); this judgement is a conscious one and so is heavily reliant on higher-order cognitive functions. The agency judgement takes into account the actual experience of the event, as well as higher-order information such as personal beliefs and social and contextual cues, of which cognitive source-monitoring is a key component.

The second major assertion is that the final experience of body agency is an integration of various inputs, including pre-reflective and reflective agency cues and external cues (Moore & Fletcher, 2012; Synofzik, Vosgerau, & Lindner, 2009; Synofzik, Vosgerau, & Voss, 2013). Importantly, the integration of these cues is likely
to be performed in a Bayesian-like fashion, where the contribution of each agency cue to body agency is determined by the reliability of that cue (Moore & Fletcher, 2012). The absence or unreliability of one particular agency cue can then be compensated for by increasing the contribution of the other cues. For example, in healthy controls, as the reliability of internal sensorimotor predictions or proprioceptive cues decreases, there is an increasing reliance on external agency cues (Moore & Haggard, 2008; Moore, Wegner, et al., 2009).

7.5.2 Impaired predictive processes: how body representation alterations contribute to our understanding of passivity symptoms

The findings of the current study provided evidence for subtypes of body agency, such that people with schizophrenia had alterations of prospective body agency but still demonstrated relatively-spared body agency timing triggered by performed actions, an absence of which was specific to those with passivity symptoms. According to the two-level account of agency, the comparator part of the forward model is only one aspect that contributes to pre-reflective agency (Moore & Fletcher, 2012; Synofzik et al., 2008). Findings from other studies show that low-level and unconscious error correction of actions is not impaired in either people with schizophrenia or with passivity symptoms and indicates that the forward model/comparator component of pre-reflective agency is unlikely to be disrupted (Delevoye-Turrell et al., 2002; Knoblich et al., 2004). The results of this thesis indicate that people who are currently experiencing passivity symptoms have changes in pre-reflective processes that are related to the forward model, namely in the prediction of the outcomes of intentions, but not necessarily with the comparator part of the forward model.

Another important subcomponent of pre-reflective agency is the spatiotemporal prediction of the sensory consequences of one’s intentions and the efficacy of predictions contained within those intentions to effect changes in downstream processes, particularly timing circuits and attenuation of sensory feedback. One of the major findings in chapter six was an apparent inability of predictive processes to activate/inhibit other brain areas in anticipation of consequences of an action in people currently experiencing passivity symptoms. Similarly, a trait-like alteration of body schema that specifically related to proprioceptive prediction was found in people with any history of passivity symptoms. The impaired proprioceptive prediction and absence of intentional binding/perceptual repulsion found in people with passivity symptoms corresponds well to previous research into the contribution of predictive processes to
body agency. Firstly, in healthy controls, the reliability of predictive cues modulates the sense of agency such that reduced predictive reliability leads to reduced intentional binding (Gentsch, Kathmann, & Schütz-Bosbach, 2012; Moore & Haggard, 2008; Wolpe, Haggard, Siebner, & Rowe, 2013). Secondly, it has been demonstrated that there is a high noise-to-signal ratio in predictive coding in people with schizophrenia, with a variability of internal motor predictions nearly double that of healthy controls (Synofzik et al., 2010). It has also been demonstrated that the predictive contribution to body agency was insensitive to actual outcomes in people with schizophrenia (Voss et al., 2010). Further, these same studies found the presence of passivity symptoms was predicted by the imprecision of predictive processes (Synofzik et al., 2010; Voss et al., 2010).

This thesis provides a possible mechanism for the impaired prediction; the alterations in body schema (inability to predict proprioceptive outcomes of an action), body image (subjective inability to determine spatial boundaries of the body) and body structural description (reduction in acuity) may provide the predictive components with inaccurate self-related spatial information. Similarly, the changes in time perception described in chapter six may impair the temporal components of predictive processes or reduce the temporal precision that is required to synchronise predictive signals from motor areas with downstream sensory areas. It is possible that the body representation alterations, and hence impaired predictive processes, are tied into abnormal dopamine transmission in schizophrenia as it has been demonstrated that dopamine transmission codes the reliability of signals (Fiorillo, Tobler, & Schultz, 2003) and that increased dopamine transmission worsens the signal-to-noise ratio in schizophrenia (Juckel et al., 2006; Rolls, Loh, Deco, & Winterer, 2008; Winterer & Weinberger, 2004).

7.5.2.1 Consequences of impaired internal predictive processes

Impaired spatiotemporal prediction and an inability of intentional signals to initiate downstream processes could have several action and body awareness-related outcomes.

Firstly, in healthy controls, the perception of the sensory outcomes of one’s actions is attenuated by suppression of activity in the primary (SI) and secondary (SII) somatosensory cortices (Blakemore, Wolpert, & Frith, 1998; Hesse, Nishitani, Fink, Jousmäki, & Hari, 2010; S. R. Jackson, Parkinson, Pears, & Nam, 2011; Parkinson et al., 2011; Shergill et al., 2013). SI and SII are likely responsible for the conscious somatosensory perception of the body, including anatomical, tactile and postural
representations (Costantini et al., 2005; Schaefer, Flor, Heinze, & Rotte, 2006; Schaefer, Heinze, & Rotte, 2005; Schaefer, Noennig, Heinze, & Rotte, 2006; Tsakiris, 2010). In people with schizophrenia, this attenuation of SI and SII does not occur and leads to hyperactivation of SII, the degree of which is positively correlated to the presence of passivity symptoms (Shergill et al., 2014). Presumably, this is due to a failure of predictive components to attenuate activity in the somatosensory areas and may explain why people with passivity symptoms experience self-tickles as intensely as externally-produced tickles (Blakemore, Smith, et al., 2000).

Secondly, as demonstrated in chapter six, the usual modulation of time perception by voluntary actions does not occur in people with passivity symptoms, indicating that motor commands do not affect timing circuits as they do in healthy controls. The phenomenological outcome of these changes may be that people with passivity symptoms do not experience voluntary actions and their perceptual consequences as if they were self-generated. Rather, actions and their perceptual consequences may be experienced more akin to perceptions that have been produced externally, resulting in confusion regarding what is self or other-generated.

### 7.5.3 Body representation alterations contribute to reduced intentionality and the sense of self

One of the difficulties of research into passivity symptoms is developing a framework that accounts for the experience of passivity for thoughts and perceptions as well as actions. The current research has raised the possibility that alterations of body representations may also contribute to all of these symptoms. One of the characteristic features of the phenomenology of passivity symptoms is reduced intentionality, the weakened sense of existing as a volitional agent that exists in and can act upon the world (Parnas, 2000; Sass, 2003; Sass & Parnas, 2003). The disorders of the sense of self, as described in section 1.7.6, are what underlie diminished intentionality (Hirjak et al., 2013; Parnas, 2000). The consequence of diminished intentionality is a reduced sense of the ability to be the initiator of all internal processes, not just voluntary actions. Although the relationship of body representations to this particular aspect of phenomenology was not directly tested in this thesis, I propose that the reduced sense of self in passivity symptoms is exacerbated, if not directly caused by, the alterations of body representations observed. Indeed, the body representation alterations in people with current passivity symptoms all involve a profound change in the experience of the sense of self, which is most clearly reflected in the higher ratings of disembodiment and
loss of physical boundaries of the body in people with current passivity symptoms. This then is a particularly important dysfunction for passivity symptoms such as thought insertion, thought withdrawal and replaced control of affect or sensations, where there is an absence of agency over internal non-motor processes.

7.5.4 Body representation alterations and impaired timing may lead to an overreliance on external cues

An important assertion of the cue integration model of agency is that, as the reliability of one set of agency cues decrease, other cues become more important in the determination of agency (Moore & Fletcher, 2012; Synofzik, Vosgerau, & Lindner, 2009; Synofzik, Vosgerau, & Voss, 2013). If the more pronounced body representation alterations in people with passivity symptoms lead to a reduction in the reliability of pre-reflective agency cues, a bias towards reflective agency and external agency cues in determining agency may develop in this particular group. There is some evidence to support this assertion from two previous studies that demonstrated a reduction in the contribution of internal motor predictions to agency in people with schizophrenia. Voss and colleagues (2010) found an increase in reliance on external agency cues in people with schizophrenia in an intentional binding task. Synofzik et al., (2010) used an agency attribution judgement and demonstrated that people with schizophrenia rely more heavily on visual feedback than internal motor prediction for agency judgements. The degree of reliance on visual feedback was positively associated with the degree of unreliability of motor prediction, with a contribution of visual information nearly double that of healthy controls. As stated in section 7.5.2, both these studies found the degree of imprecision of motor prediction was positively correlated with the presence of passivity symptoms (Synofzik et al., 2010; Voss et al., 2010).

Another finding of this thesis in chapter six, that people with schizophrenia perceive intervals to be closer together in time, could be of particular importance to the shift in importance of agency cues. Of relevance here is excessive dopamine transmission, common to people with schizophrenia, leading to the inappropriate labelling of salience to external stimuli, as described in section 1.4.2. The excessive salience leads to attention to unimportant external stimuli, the development of spurious links between unrelated events and the incorporation of these into the patient’s beliefs (Howes & Kapur, 2009). The change in the perceived salience of external stimuli may further exacerbate the weighting of external agency cues during integration of agency signals in people with schizophrenia (Moore & Fletcher, 2012). The alteration of time
perception in people with schizophrenia described in chapter 6 indicated that this clinical group perceives events to be closer together in time than healthy controls, particularly for longer-duration intervals. This raises the possibility that external events that would not normally be associated with internal events are both incorrectly attended to and are incorrectly perceived as occurring simultaneously or preceding internal events. Alternatively, as proposed by Spence (1996), the awareness of the actual movement may occur before awareness of the intention to act, the opposite of usual experience. The outcome of impaired salience attribution and timing processes is an exaggerated reliance on external agency cues, including the actions of other agents.

However, it should be noted that the impaired predictive processes and the overreliance on external agency cues occur secondarily to body representation alterations, and the excessive salience and altered time perception do not produce passivity symptoms without sufficiently altered body representations.

### 7.5.5 Cognitive source-monitoring and prior expectations

Although this thesis did not directly assess cognitive source-monitoring models, the results of this thesis are not in contradiction with previous findings regarding these models. A reconciliation of these models can be found in the cue integration account of agency. Another aspect of this account is the importance of prior expectations in determining agency. Briefly, previous experiences of both pre-reflective and reflective agency contribute significantly to how current experiences of agency are interpreted (Moore & Fletcher, 2012). Altered or biased expectations of the outcomes of intentions can feasibly lead to aberrant interpretations of those outcomes and feeling as if one is not in control of the outcomes of their intentions (Corlett, Frith, & Fletcher, 2009; Corlett, Honey, Krystal, & Fletcher, 2011; Fletcher & Frith, 2009; Wegner, Fuller, & Sparrow, 2003). After an initial experience of passivity symptoms caused by body representation alterations and altered timing processes, impaired source monitoring may contribute to the development and maintenance of explanatory delusions of the symptoms. This may occur through impairment of the social and cognitive processes that interpret the contextual cues associated with actions and thoughts and that develop the expectations associated with the implementation of one’s intentions. Again, it should be noted that a) impaired cognitive source-monitoring is non-specific, i.e. common to all people with schizophrenia and b) a specific profile of body representation alterations is needed to produce the passivity symptoms and to change the weighting of agency cues to external sources.
7.5.6 Linking body representation alterations to neuroimaging studies

Given the current findings of body representation alterations in people with specific symptom profile, I now consider the correspondence with brain structures known to be involved in body representations.

Firstly, in regards to body structural description alterations in schizophrenia, the brain structures that are most closely identified with body structural description (the left posterior parietal cortex, including posterior intraparietal sulcus and angular gyrus, and left aMPL) have been associated with schizophrenia, undifferentiated by symptom profile. A meta-analysis of 41 functional neuroimaging studies found hyperactivation of the left inferior posterior parietal cortex and bilateral hypoactivation of the posterior parietal cortex in people with schizophrenia during various tasks that assess executive function (Minzenberg, Laird, Thelen, Carter, & Glahn, 2009). Structural imaging studies have also found abnormalities in the volume of the inferior parietal cortex, particularly the left angular gyrus (Buchanan et al., 2004; Frederikse et al., 2000; J. M. Goldstein et al., 1999; Hulshoff Pol et al., 2001; Kubicki et al., 2002; Nierenberg et al., 2005; Niznikiewicz et al., 2000; Shapleske et al., 2002; Wilke et al., 2001; Zhou et al., 2007). Presumably, the alteration of body structural description found in chapter four originates in one of these cortical areas.

In regards to the finding of chapter three of an alteration of body schema in passivity symptoms, the right posterior parietal cortex, particularly the right angular gyrus, has been implicated in both body schema (Blanke et al., 2004; Grezes & Decety, 2001; Parsons et al., 1995; Vallar et al., 1999) and has been found to be hyperactive in people with passivity symptoms (Franck et al., 2002; Ganesan et al., 2005; S. A. Spence et al., 1997). The findings in the same chapter of a body image alteration could possibly be linked to the insular cortex, a region that is hypoactivated in people with passivity symptoms (Brüne et al., 2008; Farrer et al., 2004) and has been associated with body awareness generally (Craig, 2002, 2009), body ownership (Devue et al., 2007; Karnath & Baier, 2010) and egocentric representation (Fink et al., 2003).

Finally, in chapter five, an alteration of body agency that involved an absence of action-modulation of time perception (either intentional binding or perceptual repulsion) was observed in people with current passivity symptoms. A similar absence of action-modulation of time perception was induced in young healthy controls by applying rTMS to the pre-SMA (Moore, Ruge, et al., 2010). Similarly, motor excitatory potentials invoked by TMS of the SMA inhibited the sensory attenuation that normally
occurs after voluntary actions (Haggard & Whitford, 2004). These results implicate both the pre-SMA and SMA in intentional binding and suggest that the alterations of body agency seen in people with passivity symptoms may originate from this site. However, the specificity of pre-SMA and SMA changes to passivity symptoms is not clear; abnormal activity and volume of both neural regions have previously been implicated in schizophrenia by functional and structural neuroimaging studies (Exner, Weniger, Schmidt-Samoa, & Irle, 2006; Farrer et al., 2004; Guenther et al., 1994; Ortuño, Lopez, Ojeda, & Cervera, 2005; Schröder et al., 1999; Schröder, Wenz, Schad, Baudendistel, & Knopp, 1995) but few studies have investigated the relationship of these dysfunctions to symptom profiles. One study, investigating theory of mind in people with passivity symptoms, has found hyperactivation of the SMA in this subgroup, compared to controls (Brüne et al., 2008).

Overall, the pattern of body representation alterations is supported by neuroimaging studies that have implicated brain structures common to the function of body representations, schizophrenia and passivity symptoms.

In summary, these findings provide:

a) Direct support in schizophrenia for a division of agency that it into pre-reflective and reflective agency. This finding is important, as it provides validation in a population in whom agency is impaired as its core,

b) New findings of alterations in intentional processes of the pre-reflective component of agency, suggesting that forward model accounts in clinical populations (especially in relation to schizophrenia and passivity symptoms) need to be refined,

c) A specific profile of body representation alterations that appear to underlie the predictive deficits and,

d) A specific profile of body representation alterations that appear to be necessary for the occurrence of passivity symptoms.

### 7.6 Limitations of current research

Some of the limitations of this thesis have been previously discussed in the relevant sections. Nevertheless, a summary of the limitations of this thesis is given here in order to provide an overview of the strength of the model of passivity symptoms as a consequence of body representations alterations.
A general issue that has the potential to affect the interpretation of the results of this thesis is the effects of antipsychotic medication on performance on the various tasks. It is not clear whether antipsychotic medication improves or impairs cognitive performance or if there is a difference in effects between typical and atypical antipsychotics (Bilder et al., 2002; Buchanan, Holstein, & Breier, 1994; Green et al., 1997; Keefe et al., 2004; Keefe, Silva, Perkins, & Lieberman, 1998; Meltzer & McGurk, 1999; Purdon et al., 2000; Seidman et al.; Sweeney, Keilp, Haas, Hill, & Weiden, 1991). It is unlikely that the results were due to medication effects as there was no significant difference in chlorpromazine equivalents between clinical groups, no significant association of chlorpromazine equivalents to any variables tested and no significant association of cognitive performance to the variables on interest (other than the relationship of working memory with the perceived interval in chapter 6).

Another generalised limitation of the thesis was that a positive control, such as a sample of people with focal cortical lesions, was not included for validation of the neuropsychological tasks included. A further, similar limitation is that this thesis did not demonstrate the specificity of the particular body representation alterations to schizophrenia by comparing the integrity of body representations in people with schizophrenia to another psychiatric clinical sample such as major depressive disorder or autism spectrum disorder.

One limitation in the interpretation of the results was that the instruments used to assess body image in all samples, and psychosis-like experiences in the healthy control sample, were self-report questionnaires. There is a possibility that the results of the self-report questionnaires may have been a product of biases in self-disclosure, rather than true differences in the experience of the phenomena assessed. A secondary limitation was that the two measures of body image, the projected hand illusion and the body distortion questionnaire, were both self-report questionnaires and so there was no objective measure of body image as with the other body representations.

A limitation specific to chapters five and six was the assumption that, because the pushing of the button was an intentional action, participants experienced agency over their actions and the sensory outcomes during the intentional binding task. There is the possibility that older adults and people with a current history of passivity symptoms had a reduced sense of agency over the sensory outcome i.e. the tone was perceived to have occurred too quickly or slowly to be produced by the voluntary action.

Finally, the smaller sample size and subsequent reduced age range of the Pass. + group in chapter six prevented an analysis of age, despite findings of a relationship of
age to intentional binding in chapter five. Another limitation of this chapter is that it is not clear if the absence of action-modulation of time perception in the Pass. + group was a characteristic solely of people who are currently experiencing passivity symptoms, or if this disruption is related to a more acute state of psychosis (reflected in the higher SAPS score in this group).

7.7 Directions for future research

The results of the current thesis have important treatment implications. A major treatment possibility for people currently experiencing passivity is the use of repetitive transcranial magnetic stimulation (TMS). This is a non-invasive technique whereby a magnetic field generator is placed above the head of the person receiving treatment and electrical currents within the cortical region of interest are induced by the magnetic field generator via electromagnetic conduction. Low frequency (< 1 Hz) stimulation reduces cortical excitability via a long-term depression-like mechanism, (R. Chen et al., 1997; Hansenne, Laloyaux, Mardaga, & Ansseau, 2004; Muellbacher, Ziemann, Boroojerdi, & Hallett, 2000; Muller et al., 2014), while high frequency (> 10 Hz) stimulation increases cortical excitability via a long-term potentiation-like mechanism (Nakamura, Kitagawa, Kawaguchi, & Tsuji, 1997; Pascual-Leone, Valls-Solé, Wassermann, & Hallett, 1994; Radhu et al., 2013). The links between neural regions, passivity symptoms and body representations outlined in 7.5.6 identifies potential targets for specific treatment of passivity symptoms with rTMS. Specifically, the right angular gyrus activates when an action is perceived to be induced by another agent in healthy controls (Farrer et al., 2004; Farrer et al., 2003) and is hyperactivated in people with passivity symptoms (Farrer et al., 2004; Franck et al., 2002; Ganesan et al., 2005; S. A. Spence et al., 1997). The SII somatosensory cortex receives tactile information, activity of which is suppressed by predictive motor commands in healthy controls (S. A. Spence et al., 1997), but not in people with active hallucinations (Shergill et al., 2014). Further research could investigate whether low frequency TMS disruption of activity in the right angular gyrus or the SII somatosensory cortex reduces the sensation of being controlled by an external agent. A third possible target is the insular cortex. In addition to being activated in healthy controls when these people feel agency over their actions (Farrer et al., 2003; Farrer & Frith, 2002; Karnath, Baier, & Näegele, 2005; W. Lee & Reeve, 2012), the insula is closely linked to body ownership (Craig, 2009; Devue et al., 2007; Karnath & Baier, 2010), other aspects of body image (Craig, 2002; Fink et al., 2003) and is hypoactivated during self-produced movements in people with passivity
symptoms (Farrer et al., 2004). Presumably, activity could be induced in this region using high frequency rTMS, with the aim of increasing the experience of being in control of one’s movements and reducing the bodily perceptual distortions of body image in people with passivity symptoms. Although the insular cortex is a relatively deep cortical region, and standard rTMS can only influence surface cortical regions, there is deep rTMS technology available that has been shown to be effective at stimulating deep brain regions (Zangen, Roth, Voller, & Hallett, 2005).

As trait factors indicate a vulnerability to passivity symptoms, and this thesis has demonstrated some trait-like alterations of body representations in people with past experiences of passivity symptoms, it is possible that early interventions for these body representation alterations could be developed to prevent disability and distress caused by these symptoms. One such possibility would be to determine if the use of rTMS on the brain regions specified in the previous paragraph in people who have experienced passivity symptoms in first-episode psychosis could be used prophylactically to prevent reoccurrence of these symptoms.

It is also possible that clinical rehabilitation/cognitive remediation programs could be devised for people who have already experienced passivity symptoms. Given the importance of timing and time perception to agency in schizophrenia, cognitive remediation aimed at improving these aspects of cognition could be a possible way of mitigating passivity symptoms. However, at time of writing, the author is not aware of any widely-available remediation programs for timing. Another possible treatment is cognitive remediation aimed at improving motor control, motor prediction and proprioception. There are many such programs available that are used in rehabilitation following brain injury and stroke (Hayward, Barker, & Brauer, 2010; Peurala et al., 2012; Shin, Kim, Lee, & Shin, 2014; Sucaer et al., 2014; Yun, Chun, Park, & Kim, 2011; Zimmermann-Schlatter, Schuster, Puhan, Siekierka, & Steurer, 200). However, there is little literature on the use of motor rehabilitation programs in schizophrenia, with one study finding an improvement in motor function using a motor task as one of a battery of neurocognitive training tasks, although the contribution to symptoms was not examined (Wexler et al., 1997). Further research could examine if such programs are able to prevent or improve passivity symptoms.

Another issue that arises from this thesis is what causes the body representation alterations found. Many frameworks have been proposed to explain the self-disorders of schizophrenia. However, few frameworks have addressed the issue of the specificity of alterations to passivity symptoms. This thesis has demonstrated there are some body
representation alterations that are more pronounced in passivity symptoms and some of these alterations appear to be a trait-like alteration in schizophrenia. Future research needs to be directed to determine why body representation alterations occur in this pattern.

Other research questions have arisen from this thesis. Firstly, this thesis examined the association of PLE with embodiment, disembodiment, agency and proprioceptive drift during the projected hand illusion, as well as with intentional binding. As detailed in 7.3.1, proprioceptive drift is not a reliable measure of body schema; future research could examine the association of PLE with performance on the hand laterality task. Similarly, the association of PLE with performance on the two tasks assessing body structural description and with response on the body distortion questionnaire could be investigated.

The absence of an objective measure of body image provides an opportunity for further research into body image in people with passivity symptoms. A possible task for this purpose is the modified Image-Marking Procedure (Askevold, 1975; Priebe & Röhricht, 2001; Röhricht & Priebe, 1996).

Although subjective measures of agency during an intentional binding task have been assessed previously in young healthy undergraduates (Ebert & Wegner, 2010), no such measure has been adopted in studies that have assessed intentional binding in either people with schizophrenia or age-matched community controls. Given the findings of perceptual repulsion with increasing age, it is important to test the underlying assumption that people still feel agency over the sensory outcomes of their actions, even if there is perceptual repulsion between the action and outcomes.

Finally, further support for the conceptualisation of schizophrenia as a spectrum of self-disorders could be found by utilising a similar battery of tasks to the current thesis to assess body representations in relatives of people with schizophrenia, people in the schizophrenia prodrome and/or with first-episode psychoses.

7.8 Conclusion

This thesis conducted an assessment of body representations (body schema, body image, body structural description, body agency) in people with schizophrenia with a current experience of passivity symptoms, people with a past history of passivity symptoms, people with no history of passivity symptoms and a sample of healthy controls recruited from the community, age-matched to the clinical sample.
The main results were as follows:

1. Validation of the projected hand illusion and intentional binding tasks in the healthy controls found good evidence for the dissociation of body schema, body image and body agency. Association of demographic variables, such as age and sex, were found for some of the body representations. Particularly, age was associated with a decrease in intentional binding such that older adults reported the opposite effect, termed perceptual repulsion.

2. In line with the conceptualisation of schizophrenia as a spectrum of self-disturbances, people with higher levels of PLE had a more malleable body image and an alteration of body agency.

3. In relation to the clinical group, strong evidence was found for fundamental body representation alterations in all people with schizophrenia, regardless of symptom profile. This included:
   i) an alteration of body structural description that was either a reduction in the spatial acuity of the information stored in body structural description, or an impairment specific to a structural representation of the fingers, and
   ii) an alteration of prospective body agency.

4. Body representation alterations that were common to people with trait vulnerability for passivity symptoms included:
   i) an alteration of body schema that impaired the ability of this group to predict the proprioceptive consequences of an imagined movement,
   ii) an alteration of body image disembodiment such that they were more prone to body image disembodiment of their own body parts during sensory conflict, and
   iii) an alteration of body image disembodiment typified by greater experiences of a loss of the physical boundaries of the body.

5. State-like body representation alterations were found in people who were experiencing current passivity symptoms;
   i) alterations of body image (embodiment) and body agency pointing to difficulties in determining one’s own body parts and actions and,
   ii) alterations of body image (depersonalisation, loss of body boundaries and changes in perceived size of body parts) and,
iii) absence of action-modulation of time-perception, suggesting neural predictive processes are unable to effect changes in other neural areas.

Altogether, this thesis found supporting evidence for a model of passivity symptoms that states these symptoms arise from alterations of body representation (Waters & Badcock, 2010). It was proposed that these body representation alterations lead to a reduced sense of intentionality, the perceived ability of being able to produce intentions and perceptions. The body representation alterations also lead to an impairment of intentional processes that affect downstream neuropsychological processes, particularly timing circuits and sensory attenuation, the result of which is that people with passivity symptoms perceive self-made experiences as if they were externally-produced. The changes in time perception common to people with schizophrenia then impair the ability to correctly structure the temporal order of events and may lead to the perception of external events as being closely related to internal events. The final outcome of body representation alterations in passivity symptoms is the replacement of the person’s agency with that of an external agent.

Altogether, this thesis has provided empirical, neuropsychological evidence for the changes in the experience of the self in schizophrenia and passivity symptoms first identified over a century ago (Bleuler, 1911; Kraepelin, 1913), first described in detail by Schneider (1946) and expanded upon by phenomenological descriptions drawn from clinical observations of people with schizophrenia (Sass & Parnas, 2003).
Appendix I - The Rubber Hand Illusion: Manipulating our Sense of Body Experience

Abstract

Our sense of bodily-self involves an ongoing interaction of multi-sensory experiences and an integration of top-down and bottom-up processes. The perception of one's own body refers to a subjective construct that has also been termed 'corporeal awareness', ‘embodiment’ and ‘bodily consciousness’. One experimental manipulation that is well placed to investigate multiple processes underlying our sense of self, is the Rubber Hand Illusion. During this illusion participants are asked to watch a rubber hand being stroked, while their own hand is simultaneously being stroked, out of the participant's vision. The conflicting information arising from visual and tactile stimuli gives rise to an experience whereby participants report a dissociation in the location of their own hand, and the perception that the rubber hand is now an extension of their body. This particular “expansion of consciousness” comprises several experiences categorised by Longo et al. (2008). The defining experience of the Rubber Hand Illusion is the experience of “Embodiment” over the rubber hand. This experience incorporates feelings of ownership and control over the rubber hand as well as a positional experience of the rubber hand. Negatively correlated with embodiment is an experience of a loss of sensation of the participant's own hand, presumably via replacement with the rubber hand. There are also affective/emotional experiences directed towards the rubber hand that arise during the illusion. Research into the mechanisms and neural substrates of the Rubber Hand Illusion has been advancing steadily, giving us an increased understanding of the processes that make up our sense of self-experience. The follow-on effects arising from a deeper understanding the Rubber Hand Illusion offer profound insights into what happens when self-experiences are disrupted in some neurological or psychiatric conditions. For example, individuals with psychotic disorders suffer from distortions of perception that lead to difficulties in self-recognition. Neurologic conditions such as ‘alien hand’ syndrome, and out-of-body experiences, also show fundamental disruptions in body ownership and self-awareness. Similar disruptions of sensory integration can be induced in otherwise healthy people given pharmacological agents that interfere with top-down and bottom-up processes. Whether distortions are organically, or pharmacologically-induced, both lines of evidence can tell us something of the underlying neural processes that give rise to our experience of the self. The literature from the rubber-hand illusion thus provides important knowledge for understanding the processes of self-consciousness and sense of bodily-self.
Introduction

Imagine a rubber hand sitting on the table in front of you. It is obvious to you know the rubber hand is not your own, and that you would feel nothing if someone else touched it. Under normal circumstances, it is hard to imagine how the rubber hand could ever be your own. There is a procedure, known as the rubber hand illusion (RHI), used in neuroscience and psychology that can create the powerful illusion that a touch on the rubber hand is like a touch on your own skin. Furthermore, this illusion can make a person feel as though the rubber hand that they are looking at is actually their own hand.

The procedure of the RHI involves sitting with a rubber hand that is aligned in a position next to your hand but displaced by a small distance. Your hand is also obscured from sight behind a screen, so that you see the rubber hand close to where your hand should be. The experimenter then strokes both hands. If the strokes on the rubber and the real hand are well synchronised, you will most likely report the sensation that you feel the strokes where the rubber hand was, that your own hand has moved closer in space to the rubber hand, or even that the rubber hand is your own hand. Amazingly, the illusion will occur even if the rubber hand is not of the same size, colour or gender as the participant’s, or even if the participant’s hand has unique features such as warts or nail polish that are not present on the rubber hand (Armel & Ramachandran, 2003; Austen et al., 2004). Even more incredibly, under the right conditions, a hand does not need to be used at all, as simultaneous stroking of inanimate objects, like a block of wood, can induce a similar experience (Armel & Ramachandran, 2003; Hohwy & Paton, 2010).

The use of hand illusions in human psychology has a long history. The first publication to use a procedure similar to the RHI was in the first half of the 20th century; participants were made to feel as if a single fake finger, poking through a cloth covering their own hand, was their own (Tastevin, 1937). Other similar procedures have utilised prisms (Hay, Pick, & Ikeda, 1965; Mon-Williams, Wann, Jenkinson, & Rushton, 1997; Shimoio, 1987), mirrors (Ramachandran, Rogers-Ramachandran, & Cobb, 1995) or the experimenter’s hand (Nielsen, 1963; Welch, 1972) to displace the observed location of one’s hand. The RHI, in its current form, was first reported in the literature by Botvinick and Cohen (1998). Yet what can be learnt from what appears to be a simple parlour trick?

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1 Since the publication of Botvinick & Cohen's (1998) article, multiple variants of the RHI have been developed and presented in the literature. The basic premise of all variants is the stimulation of a second, non-self hand that is displaced by
The RHI can be a tool to investigate processes linked to self-recognition. This chapter provides an comprehensive review on research findings on the RHI. Specifically, we review (i) the psychological constructs that the RHI assesses, (ii) dimensional categories (phenomenology) of the RHI, (iii) the experimental measures assessed by the RHI, (iv) the links between body representations such as body image and body schema and the RHI, (v) the neural correlates of the RHI as assessed with fMRI, PET, EEG and TMS studies, and (iv) pharmacological and psychiatric studies of the RHI. Finally, we discuss the possibilities for future research.

The ‘Self’ and the Body

For the vast majority of healthy people, the perception of their body as their own is an assumed constant that occurs with little or no conscious effort. Yet our ability to function as autonomous agents is underpinned by recognising what makes up “I” and being able to distinguish between the self (a construct that forms an intermittently interrupted “stream of consciousness” making a life-long single narrative) and others. The subjective experience of the body has been variously referred to as embodiment, corporeal awareness, bodily consciousness and self-recognition (for consistency, this will be referred to as “self-recognition”; Arzy, Overney, et al., 2006; Berlucchi & Aglioti, 1997; Longo et al., 2008; Waters & Badcock, 2010). Self-recognition is a critical aspect of the self as it generates the perception of one’s self (including thoughts and actions) as residing within the boundaries of the body (Arzy, Overney, et al., 2006). The importance of self-recognition is seen in the debilitating symptoms of various disorders that affect one or more aspects of self-recognition. Examples include the complete disappearance of one half of the body from conscious awareness in people with unilateral neglect (Gallagher, 2005; Gallagher & Cole, 1995; Giumannara, Gibson, Georgiou-Karistianis, & Bradshaw, 2008), the unwanted, often bizarre, movements of a limb in people with alien hand syndrome (Biran & Chatterjee, 2004; Biran et al., 2006; Kritikos et al., 2005; Kumral, 2001), and the desire to have one’s own healthy limb amputated in people with body integrity identity disorder because the limb feels foreign (Berger, Lehrmann, Larson, Alverno, & Tsao, 2005; Dyer, 2000; First, 2005).

As can be seen from the above examples, changes can occur to just one limited aspect of self-recognition; that is, just as self-recognition is one component of the experience of the self, self-recognition itself is separable into multiple constructs.
Changes in self-recognition were first observed during the late 19th and early 20th centuries in people with epilepsy or central nervous system (CNS) lesions (Feré, 1890; Gowers, 1901; Head & Holmes, 1911/12; Lemos, 1898; Pick, 1922) but it was Head & Holmes (1911/12) who first proposed that self-recognition is divisible into separable components (for clarity these will be referred to as body representations). There are many difficulties involved in the research of self-recognition in clinical populations. Firstly, some of the evidence on disorders of self-recognition are observed in cases of pronounced trauma to the CNS or body, e.g., brain lesions due to stroke, spinal cord damage or limb amputation. Controlled, experimental manipulations of CNS trauma are unethical in humans and are difficult to replicate in animal models, if not impossible, due to the self-report nature of many aspects of self-recognition. Secondly, these disturbances are often transient in nature, making them difficult to observe when they do occur. Thirdly, while studies on clinical populations can provide valuable information about the function of the nervous system, they do not assess self-recognition during normal functioning and therefore may have limited implications for non-clinical, healthy populations. Finally, disorders of self-recognition are often limited to one aspect of self-recognition and this hinders the investigation of the interaction that occurs between multiple aspects and their contribution to self-recognition. These limitations have driven the development of experimental models that accurately and reliably assess self-recognition in healthy people. The strength of the RHI is that it is capable of manipulating both individual body representations and assessing their interactions (the nature of which will be described later). It is from being able to manipulate both categories that the RHI has become one of the most important models in the research of self-recognition.

**Phenomenology of the RHI**

The defining feature of the RHI is a feeling of embodiment of the rubber hand. The RHI is usually administered under two conditions and in both conditions the person's own hand is out of sight. The first is the synchronous condition in which the stroking of the rubber and real hands is simultaneous. The second is the asynchronous condition in which each stroke is placed on different locations of each hand and/or the strokes are not applied simultaneously. The experience of embodiment predominantly occurs during the synchronous condition such that participants report that the rubber hand begins to feel as if it is their own hand and that they feel the strokes on the rubber hand and not their own (Botvinick & Cohen, 1998). Due to the subjective nature of the
experience, a self-report assessment is given via a questionnaire containing items that aim to best represent the experience. Longo et al. (2008) constructed a 28-item questionnaire that was found to be separable into five dissociable aspects of the phenomenology of the illusion as assessed by principal components analysis. These five components are:

*Embodiment,* the experience of the rubber hand as belonging to and being part of the participant, as well as being under their control. This component can be further broken down into sub-constructs that involve feelings of agency, location and ownership over the rubber hand.

*Loss of the participant's own hand,* the reduction in perception of the participant’s own hand during stimulation.

*Movement,* relating to the perceived motion of either the participant’s own hand or the rubber hand.

*Affect,* relating to the degree of interest in, and emotional experiences towards, the rubber hand.

*Deafference,* the experience of the participant’s own hand as being less vivid than normal and a decrease in sensory perception of their own hand.

Each of the above components is dependent upon the synchronicity of the tactile stimulation; embodiment, loss of ownership and affect are all rated higher during the synchronous condition while deafference is generally rated higher during the asynchronous condition (Longo et al., 2008). The original study found movement to be rated higher during the asynchronous condition, although the opposite has been found in other studies (Albrecht et al., 2011).

A companion measure of the RHI, which has the benefit of being (somewhat) more objective, is known as proprioceptive drift. Before stroking starts, the experimenter asks the participant to, without looking, indicate where they feel their own hand to be (or more specifically, usually the middle finger) with the hand that has not been stroked and the distance between the felt location and the actual location is recorded. After stroking the participant’s hand as described before, a second measurement of the ‘felt’ location of their hand is conducted. The post-stimulation measurement is then subtracted from the pre-stimulation measurement, and any difference is termed ‘proprioceptive drift’. Synchronous stimulation typically results in the felt location of the real hand as being closer to the rubber hand, whereas there is little to no proprioceptive drift during the asynchronous condition. The degree of
proprioceptive drift is related to the length of delay between stimulation of the real hand and rubber hand; delays less than 400 ms produce drift significantly different from zero (Shimada et al., 2009) but delays above 400ms do not (Shimada et al., 2009; Tsakiris & Haggard, 2005).

There are further ways to manipulate proprioceptive drift. Firstly, proprioceptive drift can occur after as little as 4 to 12 seconds of viewing a posturally compatible rubber hand (Holmes & Spence, 2005), and this can occur without an accompanying embodiment of the rubber hand (Holmes et al., 2006; Holmes & Spence, 2007). Incremental changes in proprioceptive drift are also possible; greater drift was found for a posturally compatible rubber hand than a posturally incompatible hand, which in turn was greater than that of a wooden block (Holmes et al., 2006). Also, the degree of proprioceptive drift between synchronous and asynchronous conditions can be predicted by the rating of embodiment of the rubber hand but not by any other construct (Longo et al., 2008). Finally, proprioceptive drift is dependent upon the nature of the stimulation of the hands. If just one finger is stroked on the rubber and real hand, drift will occur for that finger only and not for non-stimulated fingers (Tsakiris & Haggard, 2005). In contrast, if the participant actively moves one of their own finger’s (as opposed to being stroked with a brush) proprioceptive drift occurs for the whole hand (Tsakiris et al., 2006).

In summary, the phenomenology of the RHI is characterised by several major constructs that are dissociable from one another: embodiment of the rubber hand, loss of the person's own hand, an affective/emotional component, perceptions of movement between the rubber hand and the person's own hand and a quantitative change in the felt location of one’s own hand.

**Body Schema, Body Image and the RHI**

As discussed previously, it has long been recognised that self-recognition is composed of dissociable body representations. Despite early attempts to clarify the situation, e.g. (Gallagher, 1986), one of the defining characteristics of current self-recognition research is that there is little consensus regarding how many body representations there are, the characteristics of each and the nature of interactions between them (see the following for reviews; de Vignemont, 2010; Dijkerman & de Haan, 2007; Gallagher, 2005; Kammers, Kootker, et al., 2010). Despite the conceptual difficulties, there are two body representations that have been well-characterised; body schema and body image.
Body schema is generally defined as an unconscious, dynamic representation of the movement and position of the limbs and body in 3D space (Cole & Paillard, 1995; Coslett et al., 2002; Gallagher & Cole, 1995; Schwoebel & Coslett, 2005). It arises from the bottom-up integration of multiple streams of sensory information, particularly the proprioceptive and tactile modalities (Gallagher & Cole, 1995; Kammers, van der Ham, & Dijkerman, 2006). By contrast, body image relates to a conscious, top-down representation that integrates bottom-up, perceptual experiences of one's body with higher cognitive functions. This includes attitudes about one’s and other’s bodies, beliefs about bodies in general and the lexical-semantic representations used to describe the names and functions of body parts and their relation to non-self objects (Coslett et al., 2002; Coslett & Schwoebel, 2002; Schwoebel & Coslett, 2005).

This description of how body schema and body image contribute to the phenomenology of the RHI will begin by discussing a common description of the bottom-up processes of sensory integration. Visual input is generally more heavily weighted than other sensory modalities during sensory integration (DiZio, Lathan, & Lackner, 1993; Hay et al., 1965; Tastevin, 1937; Witkin, Wapner, & Leventhal, 1952). Neurons that are responsive to the spatial location of body parts in the premotor and parietal cortices preferentially encode inputs that have greater spatial acuity, visual input having greater spatial acuity than proprioception (Giummarra et al., 2008; Graziano, 1999; Graziano, Cooke, & Taylor, 2000). During the synchronous condition of the RHI there is incongruent visual and tactile input and visual information is given precedence over the tactile information (termed ‘visual capture’) in integrating this mismatched information, resulting in the perceived shift of the felt location of one’s real hand towards that of the rubber hand. It has been proposed that the process that forms body schema may be a bottom-up Bayesian-type perceptual binding system. In this system, two or more perceptions are “bound” when their co-occurrence has a high probability. This probability is dependent upon the prior probabilities of this co-occurrence and the weighting of each input, both of which are a product of one’s personal history of perception (Armel & Ramachandran, 2003; de Vignemont, 2010; Kammers, Mulder, de Vignemont, & Dijkerman, 2010). The strength of this model is that it both explains how visual input shifts proprioception during the synchronous condition of the RHI and also the reduction in proprioceptive drift in the asynchronous condition; the increased delay between the visual and tactile information decreases the probability of co-occurrence and there is no perceptual binding. A third important aspect of this model is that the prior probabilities are generated by an internal model of the body that is developed.
through learning and past perception, this top-down cognitive model being an integral part of body image.

However, this common characterisation of proprioceptive drift does not match well with the empirical data. If ‘visual capture’ was an important aspect of proprioceptive drift, and visual stimuli were dominant over proprioceptive stimuli, than the proprioceptive drift should be biased towards the visual stimuli (the rubber hand) and away from the proprioceptive cues as to where the hand is. This does not usually occur. Indeed, proprioceptive drift is seldom as far as 50% of the distance to the rubber hand (E.g., 21.7% of the distance to the “rubber hand” from the real hand in the best case with synchronous stimulation with the index finger in Tsakiris et al., 2006). Thus, it appears that visual stimuli contribute to the spatial localisation of the hand when eyes are closed, but memories of the visual location do not dominate over the proprioceptive cues. As far as proprioceptive drift is concerned, it is clear that a visual spatial map contributes to the spatial localisation when eyes are closed, but does not dominate, otherwise the perceived localisation would be greater than 50% towards the “rubber hand”. Differential weighting of stimuli in favour of visual stimuli for spatial localisation may be important when the eyes are open, and for the process of embodiment (see below), but in the measurement of proprioceptive drift, “visual capture” or dominance of visual stimuli does not appear to be present, and contributes to spatial localisation in a less dominant fashion.

Embodiment, the incorporation of the rubber hand into body image, is a phenomenon that can be dissociated from other aspects of the RHI that represent body schema. Firstly, there is a distinct temporal difference between the onset of proprioceptive drift (~4-6 seconds) (Holmes et al., 2006) and the onset of the full illusion (~11 seconds) (Ehrsson et al., 2004). Proprioceptive drift also appears to continue to increase after the rubber hand has been embodied (Botvinick & Cohen, 1998; Tsakiris & Haggard, 2005; Tsakiris, Schütz-Bosbach, et al., 2007). Secondly, under certain conditions, proprioceptive drift can occur without embodiment of the rubber hand (Holmes & Spence, 2007) and embodiment of the rubber hand can occur without proprioceptive drift (Kammers, Verhagen, et al., 2009). These data add to the less significant role of visual stimuli in proprioceptive drift than in embodiment to support the view that embodiment is separable from proprioceptive drift.

So what processes underlie embodiment? Embodiment and loss of own hand are significantly correlated: as embodiment of the rubber hand increases there is a reduction in the perception of one’s own hand (Albrecht et al., 2011; Botvinick & Cohen, 1998;
Ehrsson, 2009; Longo et al., 2008). Longo et al. (2008) proposed that the embodiment of the rubber hand is achieved at the expense of perception of one’s own hand by suppressing or displacing awareness of the real hand, rather than from the addition of a supernumerary limb. In support of this, Ehrsson (2009) used two rubber hands to elicit the experience of owning three right hands. While each hand was embodied, the level of embodiment was less than that elicited from the stimulation of a single rubber hand. This indicates that the embodiment was spread over the three hands and that the neural representations of each rubber hand were competing for a part of a finite “pool” of embodiment. The duplication of a single tactile stimulus on the real hand into two stimuli on two embodied rubber hands lends further support to the probabilistic nature of the RHI; the most probable location of the real hand is estimated to be in two positions through a process that allows for bi- (or tri-) phasic distributions (Deneve & Pouget, 2004; Ma, Beck, Latham, & Pouget, 2006).

Although the RHI can dissociate between body image and body schema, it should not be assumed that illusion is dependent upon only one of the body representations. Indeed, it is apparent that dissociation of the two is only achieved under certain conditions and that the RHI, and all its individual components, is not the outcome of one process but the interaction between multiple bottom-up and top-down processes. Assessment of the interactions between body representations has mostly been achieved by manipulating the visual stimulus. An example of top-down cognitive processes (body image) shaping bottom-up sensory integration (body schema) is seen in the consistent finding that the RHI is dependent upon the orientation of the rubber hand in relation to the participant’s hand. When the rubber hand is in a position that is posturally incompatible with the participant’s hand (i.e. at a 90° angle), both the illusion and proprioceptive drift are attenuated, regardless of the synchronicity of the tactile stimulation (Austen et al., 2004; Ehrsson et al., 2004; Farne et al., 2000; Holmes et al., 2006; Pavani et al., 2000; Tsakiris & Haggard, 2005). This occurs because the angle of the rubber hand creates a mismatched representation when integrated with the visual and proprioceptive information of the participant’s real hand. When this representation is compared to the long-term representation of the hand in the body image, the incompatibility of the input results in the perception of the real hand as being in its actual location.

Other evidence from the RHI has revealed the nature of the influence of body schema on body image. As briefly discussed earlier, the RHI is resistant to the visual appearance of the rubber hand; the rubber hand can be of a different size, skin tone and
gender to the participant’s own hand and can have or lack unique characteristics such as freckles or jewellery and both proprioceptive drift and embodiment will occur after synchronous stimulation (Armel & Ramachandran, 2003; Austen et al., 2004; Longo & Haggard, 2009). Indeed, participants will often describe their own hand taking on the characteristics of the rubber hand; one participant who volunteered for the authors reported that they could feel the veins on a realistic prosthetic hand moving with their heartbeat. Taking this further, the object being stimulated does not even need to be a hand for the illusion to occur: Armel & Ramachandran (Armel & Ramachandran, 2003) were able to elicit the illusion when they replaced the rubber hand with brush strokes on a desk. Hohwy & Paton (Hohwy & Paton, 2010) were not only able to elicit the illusion on a non-hand object but also when the object was in a position that would be impossible for any normal body part. This evidence indicates that the effect of the existing body image on integrating sensory processes to arrive at embodiment is weaker than what has been suggested by Tsakiris et al. (Tsakiris, Haggard, Franck, Mainy, & Sirigu, 2005). Or, in other words, a person's body image is more labile than previously proposed. As Hohwy & Paton (2010) suggest, once there are more solutions to the “visuotactile conflict”, as can be learnt during the RHI, it becomes easier to disregard the existing internal body image model and replace it with increasingly odd and bizarre models. This is perhaps best summarised by Schwabe & Blanke (2008) and quoted by Hohwy & Paton (2010): “online processing of body-related multisensory information in the brain is more like ongoing puzzle solving of which the normally experienced embodied self-location is just a fragile and only temporarily stable solution, which is a setting that is naturally suited for the Bayesian approach to sensory information processing”.

**The Body in the Brain: Neural Correlates of the RHI**

Like all psychological, cognitive and experiential phenomena, there is a neural correlate that has the potential to be mapped onto an experience. For example, recent evidence into visual perception has shown that even a relatively crude method like functional magnetic resonance imaging, crude compared to the intricacies of the human brain, can approximately recreate what a person is looking at (Nishimoto et al., 2011). Even the complex experiences associated with the RHI, with multiple sensory and cognitive components, have a number of neural correlates that are beginning to be unravelled. Research into the underlying neural substrates of self-recognition can be particularly valuable because it is integral to social behaviours, self-consciousness and
cognition. A defining boundary between the self and other is a necessary component of 
human beings conceptualising themselves as unique agents in an “external” 
environment. The implications of disruptions of self-recognition are seen in the 
symptoms of a number of neurological and psychiatric conditions (Bromage & 
Melzack, 1974; Vallar & Papagno, 2003; Waters & Badcock, 2010; Zampini, Moro, & 
Aglioti, 2004). A deeper understanding of these processes may therefore help us to 
understand some quite complex disorders.

As mentioned previously, it is difficult, if not impossible, to have a fully 
comprehensive animal model of complex experiential phenomena. In particular, a 
model such as the RHI relies predominantly on the person reporting on their 
experience. Therefore, human studies, so far, are the only studies that can explore the 
correlates between subjective experiences and illusions and the brain, assuming that the 
self-reports have some degree of correlation with those subjective experiences. 
Research into human neural correlates of the RHI has been conducted via four main 
experimental paradigms; functional magnetic resonance imaging (fMRI) or positron 
emission topography (PET), transcranial magnetic stimulation (TMS), 
electroencephalography (EEG), and psychopharmacology. These methods have 
supported the notion of multiple dissociable but interrelated components that build self-
recognition.

*fMRI and PET studies into the RHI*

fMRI is a non-invasive imaging procedure that measures the change in blood 
flow in the brain. This change in blood flow has been closely correlated with neural 
activity as actively firing neurons have greater demands for glucose and oxygen than 
less active neurons. The signal detected by fMRI is relatively small and requires many 
repetitions of the experience or experimental manipulation to provide an adequate 
signal-to-noise ratio. The advantages of fMRI are that it is non-invasive and has high 
spatial resolution (on the order of millimetres). However, there are a number of 
disadvantages to fMRI that could confound research into the RHI, the most significant 
being that fMRI is an indirect measure of neural activity. Therefore the evidence gained 
from fMRI is largely correlational. This can make it difficult to appropriately infer 
causation because there may be other non-neural processes (E.g., regulation of 
cerebrovasculature) that give similar signals. There are also significant issues relating to 
false-positives. One paper found that it was possible to get a statistically significant 
fMRI signal from a dead salmon exposed to emotionally salient stimuli (Bennett, Baird,
Miller, & Wolford, 2011). It is not likely that dead salmon exhibit emotional processing or any sort of processing for that matter.

A series of experiments by Ehrsson et al. (Ehrsson et al., 2005; Ehrsson et al., 2004; Ehrsson, Wiech, Weiskopf, Dolan, & Passingham, 2007) into the fMRI correlates of the RHI found that the reported experience of embodiment was significantly correlated with increased activity in the ventral premotor cortex. Similar findings were made in a purely somatic version of the RHI (see Ehrsson et al., 2005 for a description of the somatic RHI). Ehrsson et al. (2007) later found that threatening the rubber hand by making stabbing motions with a needle elicited activity in brain regions related to the experience of anxiety. Furthermore, the strength of the anxiety-related response was correlated with the illusion-induced activity in the premotor cortex. A similar correlation was observed between the insula and left intraparietal cortex (Ehrsson et al., 2005; Ehrsson et al., 2004; Ehrsson et al., 2007).

In discussing their findings, Ehrsson et al. (2004) note that the premotor cortex is a good candidate for the neural centre of the multisensory representation of one's body. The premotor cortex is anatomically connected to visual and somatosensory areas (Rizzolatti, Luppino, & Matelli, 1998) and it is known that activity of premotor neurons is increased when the hand is touched or when visual stimuli are near the hand (Graziano, Yap, & Gross, 1994; Lloyd, Shore, Spence, & Calvert, 2003). Ehrsson et al., (2004) suggest that during the initiation of the RHI, the premotor activity may be reflective of the resolution of conflicting visual representations of the hand with internal somatosensory representations.

In an analogous measure to that used by Ehrsson et al., Tsakiris et al., (2007) have used PET scans to investigate the neural correlates of the RHI. This measure is sensitive to radioisotope decay, and participants taking part in cognitive neuroscience studies are typically injected with fluorodeoxyglucose, a radioactive glucose substitute. When neurons are active, they use up glucose, and blood flow is increased to the active neurons to replenish glucose stores. Fluorodeoxyglucose gets taken up as a glucose substrate into these regions, where a PET scanner can measure the increase in radioactive decay. Using PET, Tsakiris et al. (2007) have found increased activity in the right posterior insula and right frontal operculum that correlated with proprioceptive drift. Increased activity in the posterior insula has been found to occur when actions are attributed to oneself (Farrer et al., 2003; Farrer & Frith, 2002; Tsakiris, Schütz-Bosbach, et al., 2007) and is also related to representations of egocentric reference frame and first person perspective (Fink et al., 2003). However, it should be noted that drawing
relationships between brain areas and embodiment based upon proprioceptive drift may not yield an accurate interpretation of the correlates of embodiment. While proprioceptive drift is usually correlated with embodiment and there may be a certain amount of overlap between the constructs, they are not always related as described above. For another example, Morgan et al. (2011) found the usual increase in embodiment after synchronous vs asynchronous stroking but found no such effect on proprioceptive drift. Further, as will be described below, TMS and psychopharmacological agents can differentially affect these measures. Indeed, dissociation amongst self-recognition constructs has been one of the central themes of this chapter and in a number of the research papers already cited.

Transcranial Magnetic Stimulation studies

TMS is a method to affect electrical currents in the brain via induction with a strong, reasonably well targeted, magnetic pulse. TMS is particularly useful because it is a direct manipulation of the cerebral cortex and therefore it is much easier to draw causative relationships. Furthermore, in contrast to direct intracranial electrical stimulation of the cortex, there is no need for highly invasive surgery to manipulate cortical activity. It is difficult for TMS, however, to target brain tissue deeper than the surface of the cortex. A single pulse of TMS, at a sufficient intensity, induces a depolarisation event. This can result in secondary neural activity generated in response to the TMS pulse (E.g., TMS over the motor cortex can invoke an involuntary muscle twitch). There are also repetitive TMS methods (rTMS) that can activate or inhibit the underlying cortical tissue depending on the parameters of the stimulation. Inhibition generally occurs with slow stimulation rates of approximately one Hz (one TMS pulse per second), whereas activation can occur at higher stimulation frequencies. The most commonly used type of rTMS to investigate the neural correlates of the RHI involves the inhibitory type to evoke a pseudo/virtual-lesion. This lesion is temporary and no acute or permanent cortical damage occurs. With this method, it is possible to study what effect removing, or suppressing, a particular part of the cortex has on illusory perception and self-recognition.

Using this inhibitory rTMS technique above the inferior parietal lobe, a junction that is makes up the superior portion of an area called the temporo-parietal junction (TPJ), Kammers et al. (2009) demonstrated a dissociation between the constructs of embodiment and proprioceptive drift. In this study, rTMS over the TPJ was contrasted
with sham rTMS. After active rTMS, participants reported the same level of embodiment as the sham rTMS, but they showed marked reductions in proprioceptive drift immediately after the conclusion of RHI stimulation. However, after proprioceptive update (initiated by a series of active reaching perceptual judgements, where the participant reached for a point in space), there was no difference between the real and sham rTMS on proprioceptive drift even though there was significant proprioceptive drift compared to the asynchronous condition. The authors suggest that the inferior parietal lobe (or TPJ) is involved in immediate perceptual relocation of our body (proprioceptive drift) but not for eventual relocation. The restored proprioceptive drift after motor activation with the person's hand may be due to the interaction between motor and perceptual systems allowing an update of the body representation normally subserved by the TPJ (Kammers, Verhagen, et al., 2009).

**Electroencephalographic studies of the RHI**

The EEG records electrical activity as it occurs on the scalp of the person. This electrical activity is comprised of a number of sources including muscles of the neck and jaw, muscles of the eyes and the electrical activity that is generated by the brain. The EEG signal that is generated by the brain is a summation of many neurons acting in unison. This is the primary advantage of the EEG; it records electrical activity of the underlying neural events as they happen. The high temporal resolution that accompanies the EEG is on the order of milliseconds, compared to the temporal resolution of fMRI, which is measured in seconds (it should be noted that it is not the MRI that has the delay, it is the underlying hemodynamic response that delays the resolution). Such a high temporal resolution can give an index of the many different stages that occur during stimulus processing, from the very early and basic sensory activity that occurs between 0 and 100 ms post-stimulus onset, to higher order contextual integration of stimuli occurring 300 ms and onwards. However, EEG signals suffer from poor spatial resolution. This is an ongoing problem within the EEG field; how do you accurately identify a source of cortical activity when there are an infinite number of source possibilities that could make up the signal that is observed on the scalp?

EEG studies into the RHI have generally been event-related potential (ERP) experiments. This is a method that repeats the stimulus presentation to the participant

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2TMS machines make a clicking sound when they send out magnetic pulses. Therefore, sham TMS has often involved holding a non-active or magnetically shielded coil over the same position while the TMS machine activates to make the same clicking sounds but without a magnetic pulse reaching the brain.
(anywhere between 15 to 1000 times) and the resulting EEG is epoched and averaged with reference to the stimulus onset, reducing the amount of “noise” or ongoing cortical activity in favour of isolating the time-locked signal. Press et al. (2008) found an enhanced negative ERP component, 140 ms after synchronous visual and tactile stimulation compared to asynchronous stimulation. This enhanced component was also elicited when the object being stimulated was a non-hand object, suggesting that the early ERP component is independent of top-down body representations. They also found effects on later ERP components, from 200 ms onwards, where a sustained negativity was found for trials where the rubber hand or object was on the same side as the participant's hand that was being stimulated. These later effects suggest a role for the effect of top-down processes on visuotactile integration. As the authors admit, even though the methodology that they used was similar to past successful attempts at inducing the RHI, correlating this ERP component with the experience of embodiment over the rubber hand or object is uncertain, particularly when they administered no questionnaire on illusory experiences. However, their results and interpretations appear to be consistent with the results of Armel & Ramachandran (2003) and Hohwy & Paton (2010).

Given that it is multimodal integration that is the driving force behind the RHI, it is not surprising that an EEG correlate of sensory integration has been investigated in relation to the RHI. 40 Hz (gamma) neural electrical activity is suggested to be a correlate of perceptual integration and conscious perception (Engel & Singer, 2001; Melloni et al., 2007; Singer & Gray, 1995). Kanayama et al. (2007) found increased phase synchrony amongst electrodes at 40 Hz frequencies during synchronous stimulation compared to the control conditions. An increase in phase synchrony indicates that separate areas of the brain are firing/oscillating with more consistency at higher (~ 40 Hz) frequencies. This implies that there is more communication between brain areas during synchronous stimulation compared to asynchronous stimulation. However, there was no correlation between 40 Hz synchrony and subjective reports of the strength of the illusion. A lack of correlation is likely due to there being a small sample size (n = 10) and an overly simple questionnaire to adequately encompass the full experience of the illusion. Despite this limitation, 40 Hz oscillations in the brain likely represent the “cross-talk” between brain regions that is necessary for integrating information across sensory modalities.
Psychopharmacological Studies of the RHI and its Relation to Psychosis

Another useful method for investigating the neural substrates of self-recognition is to administer a drug with well-characterised actions and then see how that drug interacts with the various behavioural, psychological and cognitive processes. The targets of most psychopharmacological agents are the chemical transmission events that occur within the synapses. From within the synapse there are a number of ways that both pre- and post-synaptic processes can be modulated by drugs to result in changes to post-synaptic electric potential summation. The effect of this is to either increase or decrease the chance of generating an action potential so that a particular neuron fires. In this manner drugs are a useful method to investigate the chemical signalling systems of the brain. However, the specificity of a drug can be a limiting factor in the quality of information that can be gained. For example, a drug like alcohol has very low specificity for any chemical system. The primary targets of alcohol are GABA receptors, NMDA receptors and Ca\textsuperscript{2+} channels. The first two targets are two of the most numerous receptors in the central nervous system and Ca\textsuperscript{2+} channels are the very basis by which neurons release neurotransmitters to interact with post-synaptic neurons. Therefore, alcohol is not a good drug to investigate specific neural systems because it is likely to affect every neural system.

Psychopharmacological studies are particularly useful for studying psychiatric disorders. Some disorders, like schizophrenia, have hypotheses that link symptoms to either specific neural systems or specific receptor targets. In schizophrenia, there is a robust hypothesis that positive psychotic symptoms, i.e., hallucinations and delusions, are a result of dopamine hyperactivity (Beninger, 2006; Howes & Kapur, 2009). There are a number of reasons for this, but chiefly among them is the fact that all current medications that are used to treat psychosis are dopamine D\textsubscript{2} receptor antagonists (or partial agonists) (Horacek et al., 2006; Seeman, 2006), drugs that activate dopamine receptors or increase synaptic concentrations of dopamine can induce psychosis (Angrist & Gershon, 1970; Damásio et al., 1971; McCormick Jr & McNeel, 1963; Ruggieri, Stocchi, Carta, & Agnoli, 1989), and people with schizophrenia display a number of alterations in pre-synaptic dopamine concentrations which have been shown to correlate with positive symptoms (Breier et al., 1997; Laruelle & Abi-Dargham, 1999; Laruelle, Abi-Dargham, Gil, Kegeles, & Innis, 1999; Laruelle et al., 1996).

Interestingly, it has been demonstrated that people with schizophrenia have an increased illusory response to the RHI and an onset of the illusion five times faster than that of controls (Peled et al., 2003; Peled et al., 2000). The RHI items that patients rated
significantly higher were related to experiences of embodiment and ownership over the rubber hand. In addition, embodiment ratings correlated significantly with hallucinatory symptoms (and positive symptoms more generally), as measured by the PANSS, but there were no relationships between the RHI and negative symptoms. The authors suggest that it is a reduction in top-down “connectivity” that leads to an increased illusory experience because this would result in less modulation over the “false overconnections” that occur during the bottom-up processes of the RHI (Peled et al., 2000). Within the wider context of psychosis and the RHI, they suggest that mechanisms responsible for positive psychotic symptoms may have overlaps with mechanisms causing the enhancement of the RHI.

As mentioned previously, the preeminent model of positive symptoms of psychosis is the dopamine model. As such, dopamine transmission may be a common mechanism that subserves both positive psychotic symptoms and increased illusory experiences found in people with schizophrenia during the RHI. In addition, it was mentioned previously that the primary brain region associated with embodiment of the RHI is the premotor cortex (Ehrsson et al., 2004). One of the major dopamine neural bundles has projections that innervate this area (Bergson et al., 1995; Goldman-Rakic, Lidow, & Gallager, 1990). To investigate the role of dopamine on the RHI, we gave healthy participants a dopamine-releasing agent, dexamphetamine, and assessed the RHI at a time near the peak of the plasma levels (Albrecht et al., 2011). When participants were administered dexamphetamine, they reported stronger illusory effects compared to when they were administered a placebo. Further, the construct that seemed most affected by dexamphetamine was the embodiment construct, much like that found in people with schizophrenia. In order to link these findings together, it is important to shed light on the role of dopamine in the brain. Currently, the major hypothesised role of dopamine is to attribute importance to stimuli that predict important events (Hollerman & Schultz, 1998; Robinson & Berridge, 1993, 2000; Schultz, 2007), by encoding differences between expected outcomes and actual outcomes, called prediction errors (Gradin et al., 2011; Waelti, Dickinson, & Schultz, 2001). In schizophrenia this system has been hypothesised to be faulty, leading to the inappropriate attribution of importance to otherwise unimportant stimuli (Howes & Kapur, 2009). Symptoms, like delusions, arise as a result of the cognitive explanation for this strange attribution of importance (Beninger, 2006; Kapur, 2003). With respect to the RHI, subjects are asked to focus on the visual stimulus of the rubber hand being stroked. The increased synaptic
concentration of dopamine facilitates the attribution of causal significance to the predictive visual stimulus that occurs at the time of felt stimulation.

If taken within the context of a Bayesian perceptual learning process (Armel & Ramachandran, 2003; de Vignemont, 2010), it seems likely that dexamphetamine is facilitating the component that binds stimuli together, by promoting the prediction-error learning of associations. There are a number of probable molecular mechanisms that could be candidates for this process. For example, a Hebbian account of learning (Hebb, 1949) suggests that the binding together of new neural cell assemblies, or networks, can arise from simultaneous neural activity from divergent sources as long as they co-occur together with high probability. The process by which this occurs is via strengthening the synaptic connections between neurons via long-term potentiation (LTP) (Cooper, 2005; S. J. Martin, Grimwood, & Morris, 2000). LTP is a neurophysiological process whereby there is lasting enhancement of signalling between two neurons and is currently regarded as one of the leading neural processes that subserves plasticity, learning and memory (Bliss & Collingridge, 1993; Lynch, 2004). Dopamine has been demonstrated to be an important mediator of these molecular learning processes. There has been much research linking particular sub-types of dopamine receptors with learning, memory and LTP (Castner & Williams, 2007; Centonze, Picconi, Gubellini, Bernardi, & Calabresi, 2001; Seamans, Floresco, & Phillips, 1998; Xu & Yao, 2010) as well as evidence linking dopamine with Hebbian type learning (Shen, Flajolet, Greengard, & Surmeier, 2008).

However, the dopamine model of schizophrenia is not the only model of schizophrenia. The N-methyl-D-aspartae (NMDA) receptor hypofunction model is another useful model to investigate neurophysiological processes underlying schizophrenia. The core component of this model is that the administration of an NMDA receptor antagonist to healthy participants results in similar cognitive disturbances and symptomatology to that of schizophrenia (Javitt & Zukin, 1991; Olney, Newcomer, & Farber, 1999; Phillips & Silverstein, 2003). Initially, it was the drug phencyclidine (PCP) that alerted psychiatrists and researchers to the psychotomimetic effects of NMDA antagonists (Luby et al., 1959). However, due to its long history of use in medicine and a well-characterised safety profile, more recent studies use the similar NMDA antagonist ketamine to model schizophrenia-like symptoms. For example, in a comprehensive study into the psychotogenic effects of ketamine in healthy participants, Krystal et al. (1994) found increased positive and
negative symptoms as well as cognitive deficits in a number of neuropsychological tests that are similarly reduced in schizophrenia.

The NMDA receptor hypofunction model has also been investigated with the RHI. Morgan et al., (2011) administered an intravenous dose of ketamine to healthy participants and found increased embodiment of the rubber hand and increased proprioceptive drift compared to placebo. The authors suggest that because both ketamine administration (Páleniček et al., 2011) and the RHI (Kanayama et al., 2007) are associated with an increase in 40 Hz EEG activity, 40 Hz enhancement by ketamine could lead to increased cross-modal binding between the visual and tactile modalities. If this were the case, then it may also be an explanation for the findings in participants given dexamphetamine. In separate studies, we have found that dexamphetamine increases two differently elicited measures of 40 Hz activity in healthy participants (Albrecht et al., In review; Albrecht et al., In review).

Interestingly, in both the study on ketamine and the RHI and our study using dexamphetamine, the illusion during the asynchronous stroking condition was significantly enhanced. The RHI is typically weaker in the asynchronous condition because there is a reduced correlation of the visual and tactile inputs, making it harder to draw a causal relationship. Our interpretation of this finding was to suggest that dexamphetamine interferes with the perceived timing of the brush strokes (Albrecht et al., 2011). The consequence of this would be that the brush strokes appear to the participant to be closer together in time, reducing the cross-modal discrepancy. In relation to models of psychosis, people with schizophrenia have been shown to experience the flow of time differently than healthy people (Waters & Jablensky, 2009) and larger inter-stimulus intervals are needed between two stimuli to experience them as “one-after-the-other” (Foucher et al., 2007; Giersch et al., 2009). However, Morgan et al., (2011) provided a very different interpretation. They suggested that it is the ketamine-induced augmentation of gamma activity leading to increased cross-modal binding that increases the RHI during asynchronous stroking. Neither of these possibilities can be excluded on the basis of current evidence; both are consistent with each other and are not mutually exclusive. Solving this problem will be an issue for future research and is outlined in the following section.

Convergence of Findings and Future Studies

There are a number of areas of research that would lead towards a better understanding of the neural systems involved and promote convergence of various
findings towards a unified theory of the RHI. If the ventral premotor cortex is the neural area that is largely responsible for the experience of the rubber hand as belonging to the individual, then the strength of the fMRI signal should also increase during manipulations that increase the strength of the RHI. Of the manipulations that have been discussed in this chapter, an increased ventral premotor signal should appear when participants are undergoing the RHI after the administration of dexamphetamine and/or ketamine. Further, people with schizophrenia should also show increased ventral premotor activity during the RHI. The ventral premotor cortex findings would gain further support if direct manipulations of the premotor cortex resulted in alterations to the experience of ownership over the rubber hand. One particularly useful method that has been discussed in this chapter is inhibitory rTMS which can create virtual lesions of particular cortical regions near the surface. An inhibitory rTMS lesion to the ventral premotor cortex should result in reductions of embodiment of the rubber hand. Furthermore, if there were simultaneous decreases in ratings of other aspects of the RHI (e.g. agency or ownership), then it would suggest that successful multimodal integration in the ventral premotor cortex may be a necessary condition for the occurrence of the RHI, and that this cortical area may be a “gateway” between top-down and bottom-up representations of the hand.

In addition to increased and/or intact ventral premotor cortical activity being necessary for the experience of ownership during the RHI, there should also be increases in the two EEG/ERP parameters that have so far been linked to the RHI. The first ERP finding of a long-latency enhanced negative ERP after synchronous, but not asynchronous, visual and tactile stimulation during the RHI should also occur in response to drug treatments resulting in increased illusory experiences and in patient groups that show increased illusory effects, i.e., schizophrenia. Indeed, Peled et al., (2003) has demonstrated an increase in the long latency ERP in people with schizophrenia in response to the RHI. Similar findings in people administered ketamine and dexamphetamine would support the involvement of this particular evoked potential in the RHI. The second ERP finding of increased high frequency cortical synchronisation should be similarly affected by drug treatments. In particular, if the role of high frequency cortical activity is to bind sensory experiences together, an increase in this activity would be necessary for the induction of the RHI (Kanayama et al., 2007). To support the hypothesis of Morgan et al., (2011), that ketamine increases the RHI during both synchronous and asynchronous stroking due to its effects on high frequency
activity, the increased RHI effect would need to be correlated with high frequency cortical activity.

The findings of increased illusory activity in people with schizophrenia are especially interesting. However, there is, as yet, no sign or symptom that is specific/exclusive to schizophrenia and in many situations it is more informative to discuss specific symptoms, rather than a disease as a whole. One example of this is the effectiveness of antipsychotic medications for treating positive psychotic symptoms in comparison to their small or negligible effect on negative and cognitive symptoms of schizophrenia. In relation to the RHI, it is very unlikely that an increase in embodiment during the RHI is unique to schizophrenia. With evidence linking the effects of dexamphetamine and ketamine with an enhanced RHI this points to the possibility that it is specifically positive symptoms that may be linked to increased embodiment of the RHI. Therefore, positive symptoms of psychosis related to psychiatric disorders, such as bipolar disorder, or even perhaps schizotypal personality disorder and first-degree relatives of people with schizophrenia may show increased RHI effects.

There are a number of classes of drugs that have yet to be investigated in relation to the RHI. The effects of psychedelic drugs would be a fascinating avenue for further research. Such drugs have been reported to increase ratings on a scale known as “oceanic boundlessness” (Dittrich, 1998; Vollenweider, Leenders, Oye, Hell, & Angst, 1997). The oceanic boundlessness scale measures derealisation phenomena and ego-dissolution associated with a pleasurable emotional state. In particular, ego-dissolution refers to dissolving the usual boundaries that make up the perception of where our bodies are as well as a feeling of unifying with the cosmos. It seems likely that drugs that increase this kind of perception would also lead to increased ratings of embodiment during the RHI. That is, if one of the primary effects of a drug is to increase a subject's spatial field/incorporation of vast quantities of external reality into consciousness (or at least give that impression), then it would be relatively simple to incorporate a rubber hand into a subject's body image. Lastly the evidence that a dopamine-releasing agent and an NMDA receptor antagonist similarly affect the RHI seems irresistible from a psychopharmacological point of view. Would a dopamine antagonist, or an NMDA agonist result in opposite effects on the RHI, i.e., a reduction in embodiment? Further, the interaction between these two neurotransmitter systems on the RHI is also still unknown. Previous research has found a synergistic effect of combined dexamphetamine and ketamine administration on other neuropsychological measures (Krystal, Perry, et al., 2005) but it is not known if this effect is due to the action of the
drugs on separate or common pathways. Evidence for a common pathway between the two neurotransmitter systems could be found if a dopamine antagonist or NMDA agonist attenuated the increased RHI induced by an NMDA antagonist or dopamine agonist, respectively.

**Conclusion**

Self-recognition is a critical aspect of the self as it generates the perception of one’s self (including thoughts and actions) as residing within the boundaries of the body (Arzy, Thut, et al., 2006). Notably, this is disturbed in people suffering from psychosis and in healthy people when they are given psychotomimetic (psychosis-mimicking) drugs. The research on the RHI may tell us something about the mechanisms by which self-recognition may be distorted. Susceptibility to positive symptoms, such as delusions and hallucinations, may be especially well indexed by alterations in the RHI. In particular, symptoms where the perception of the self extends well outside the body, or where one's thoughts might be perceived as leaking outside the body, or where actions that have nothing to do with the person are attributed the person, might be usefully investigated by the RHI. Hallucinations are a somewhat converse phenomena, whereby experiences that occur entirely within the body are interpreted to be originating from outside the body. As Hohwy & Paton (2010) suggest, the transition from unusual experiences to delusional beliefs might be facilitated by a fragile body image which is able to be explained away easily in response to conflicting information and excess importance is attributed to sensory integration rather than on top-down influences. Given that two pharmacological agents used to investigate schizophrenia have found comparable RHI effects to that found in people with schizophrenia, and that these drugs increase the experience of the illusion during the control condition (asynchronous stroking), this suggests that alterations in dopamine and/or NMDA receptor function may aid in the development of these strange experiences. How this mechanism occurs, either through increased learning at a molecular level, increased cross-talk as measured by high frequency oscillations or via some other mechanism that involves the seemingly critical premotor cortical region for enhanced RHI effects awaits to be seen.
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