When one's sense of agency goes wrong: Absent modulation of time perception by voluntary actions and reduction of perceived length of intervals in passivity symptoms in schizophrenia

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Abstract:

Passivity symptoms in schizophrenia are characterised by an absence of agency for actions, thoughts and other somatic experiences. Time perception and intentional binding have both been linked to agency and schizophrenia but have not been examined in passivity symptoms. Time perception and intentional binding were assessed in people with schizophrenia (n = 15 with, n = 24 without passivity symptoms) and 43 healthy controls using an interval estimation procedure (200, 400 and 600 ms intervals) with active, passive and observed movements. People with passivity symptoms did not display action-modulation of time perception, while those without passivity symptoms estimated intervals to be the same after active and observed movements. Additionally, both clinical samples reported intervals to be shorter with increasing interval length. We propose that impaired predictive processes may produce an overreliance on external cues and, together with shorter perceived intervals, lead to the subjective loss of agency.

Keywords: Schizophrenia, passivity symptoms, agency, intentional binding, time perception

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, Goetz, Yale, Corcoran, & Malaspina, 2005; McGorry, Bell, Dudgeon, & Jackson, 1998), functional brain imaging evidence (Franck, O'Leary, Flaum, Hichwa, & Andreasen, 2002; Shergill et al., 2014; Spence et al., 1997), heritability evidence (Cardno, Sham, Farmer, Murray, & McGuffin, 2002) and neurocognitive theoretical frameworks (Graham, Martin-Iverson, Holmes, Jablensky, & Waters, 2014; Maruff, Wilson, & Currie, 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 seen in passivity symptoms (Graham et al., 2014; Spence, 1996; Waters & Jablensky, 2009). Timing mechanisms are 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 of actions 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; Spence, 1996). Dysfunctions in these mechanisms, by contrast, may cause distortions in both self-monitoring processes and subjective experiences of action causation (B. Martin et al., 2014).

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 is crucial to the processes that associate causation between mental and external events (Haggard, Clark, & Kalogeras, 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; 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; 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 (Lee et al., 2009; Roy, Grondin, & Roy, 2012).

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 (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 also 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. This occurred 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.

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/s (Haggard et al., 2002). This contraction of time occurs only after self-produced actions and not after actions caused by external agents (Engbert, Wohlschläger, & Haggard, 2008). As such, intentional binding is specific for internal motor representations of self-produced actions. It has been proposed that, by reducing the perceived time between an action and its consequence(s), intentional binding reduces the variability of the prediction interval and increases action – effect contiguity (Wenke & Haggard, 2009). In turn, this allows more reliable inferences of causality and thus agency discrimination (Eagleman & Holcombe, 2002). 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, in healthy controls, intentional binding is a measure of the efficacy of motor commands to affect downstream neural processes, including timing circuits (Moore, Middleton, Haggard, & Fletcher, 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, Posada, Pichon, & Haggard, 2005; Haggard, Martin, Taylor-Clarke, Jeannerod, & Franck, 2003; Voss et al., 2010).

A limitation of two of the three studies (Haggard et al., 2003; Voss et al., 2010) is the 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 (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), but no changes in representations of external body parts, in people with passivity symptoms (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 agency disturbances specifically through processes triggered by efferent signals or if there are more general agency attribution deficits. Additionally, the three previous studies investigating intentional binding in schizophrenia have employed the Libet clock method (Libet, Gleason, Wright, & Pearl, 1983). In this task, participants are required to make timing judgements of the onset of an action or a consequent tone on separate trials, hence requiring participants required to focus on either actions or consequences, but not both simultaneously (Engbert et al., 2008; Moore, Lagnado, Deal, & Haggard, 2009). A second method, the interval estimation procedure, avoids this issue by asking participants to estimate directly the interval between an action and a sensory outcome. To our best knowledge, the interval estimation procedure has not been used to assess intentional binding in schizophrenia previously.

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 using the interval estimation procedure 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.

2. Methods

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 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 Services Human Research Ethics Committee.

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 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 (case note reviews indicated eight participants in this group had experienced passivity symptoms in the past). Independent classification of patients into groups was conducted by two of the investigators (KGS and FW).

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, Howieson, Loring, Hannay, & Fischer, 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. In both the Active and Passive conditions, participants were instructed to focus on their hand and the spacebar for every trial and care was taken to ensure participants carried out this instruction. 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 by 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 that they were to estimate the time that elapsed between the keypress and the sound that would play in the headphones. The participants were instructed to report their answer in milliseconds and that every trial would be less than 1 second and greater than 0 seconds. They were reminded that $1\text{ s} = 1000\text{ ms}$, $0.5\text{ s} = 500\text{ ms}$ etc., and that any answer between 1 and 999 was acceptable. 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 triggered by button press itself and each interval 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.

3. Results

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, Bates, DebRoy, Sarkar, & the R Development Core Team, 2013) and 'car' (Fox & Weisberg, 2011). Analyses were performed using linear mixed-effects models with perceived interval (ms) 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. Chlorpromazine equivalents, SAPS and SANS composite scores were included as fixed effects but, as there were no significant main effects or interactions, were subsequently removed from the final model. The random effects term had random participant effects with a nested movement condition by interval interaction. To test the homogeneity of variance, Brown-Forsythe tests were performed comparing the variance of each group at each level of the interval (see Table 2 for standard deviations and results of the Brown-Forsythe tests). These tests found unequal variance between groups at each level of the interval. Consequently, the final model contained a specified variance structure by fitting a variance model with different variances for each level of interval and group by specifying weights for the unequal variances. 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.

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

The ANODEV revealed no main effect of group ($F(2, 79) = 2.19, p = 0.33$) but there was a main effect of movement condition ($F(1, 635) = 10.3, p = 0.006$), with the Passive condition being perceived as shorter than Other and Active conditions, and a main effect of interval ($F(1, 635) = 517, p < 0.0001$), with participants reporting an increase in the perceived interval with longer intervals.

The group by interval interaction was also significant ($F(2, 635) = 23.2, p < 0.0001$). This interaction can be seen in Figure 1. The slopes ($\pm$ standard error) were Controls (0.64 ± 0.06), Pass. – (0.50 ± 0.08) and Pass. + (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. + ($p = 0.05$), 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, perceived the interval to be shorter compared to controls.

The group by condition interaction neared, but did not reach, significance ($F(4, 635) = 8.69, p = 0.069$). Given the p -value and our *a priori* hypothesis that there would be changes in intentional binding in both groups of people with schizophrenia, we decided to run interaction contrasts. The interaction can be seen in Figure 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 been demonstrated previously to be related to the age of the participants (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 for Pass. + (all $p > 0.05$). The three-way interaction between group, movement condition and interval was not significant ($F(8, 635) = 1.40, p = 0.84$).

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.

3.3 *Relationship of working-memory to time perception*

Given similar slopes were found in people with schizophrenia, with and without passivity symptoms, in the previous section 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 ($\pm$ SEM) was lower in people with schizophrenia (6.54 ± 0.32) compared to controls (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 ($F(1, 76) = 82.1, p < 0.0001$). The interval by backwards digit span interaction was also significant ($F(1, 76) = 10.4, p = 0.001$). As can be seen in Figure 3, as the interval increased to 400 and 600 ms, 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.

3.4 Analysis at 200 ms interval

One of the findings of section 3.2 was that Pass. - perceived intervals after Active movements to be longer than after Passive movements. We have previously demonstrated in the same sample of healthy controls as the current study that, at the 200 ms interval, younger adults experience intentional binding but this relationship changes with age such that older adults experience intervals after Active movements to be longer than after Passive movements, so-called ‘perceptual repulsion’ (Graham et al., 2015). We were therefore interested if increasing age was also responsible for the perceptual repulsion observed in Pass. -. Additionally, the increased variance in interval estimates (see section 3.1) and relationship of working memory to time perception in people with schizophrenia, as well as the general increase in variance in interval estimates with increasing interval length, suggests that interval estimations become more unreliable with increasing interval length (see section 4.6 below for a full discussion of this issue). Accordingly, we performed a final linear mixed-effects model with the 200 ms interval data, where there was less potential interference from increased variance. In this model, interval estimations (ms) were the independent variable with group, age and movement condition included as fixed effects. A significant main effect of group was found in this analysis ($F(2,76) = 6.51, p = 0.04$) with Pass. - reporting the intervals to be longer overall than the other two groups. There were no significant main interactions of age ($F(1, 76) = 0.06, p = 0.81$) or movement condition ($F(1, 150) = 0.41, p = 0.82$) or a significant interaction between group and age ($F(2, 76) = 3.47, p = 0.18$). There was a significant group by movement condition interaction ($F(4, 150) = 9.76, p = 0.04$). The three-way group by age by movement condition interaction was not significant ($F(4, 150) = 3.84, p = 0.43$). Most importantly, the age by movement condition interaction was also significant ($F(2, 150), p = 0.003$). As can be seen in Figure 4, younger individuals perceived intervals in the Active and Other conditions to be shorter than intervals in the Passive condition but this relationship changed with increasing age such that older individuals reported intervals in the Active and Other conditions to be longer than intervals in the Passive condition.

4. Discussion

The aim of the current study was to assess time perception after three types of actions (active, passive, and observed movements of an 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. 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 length in people with schizophrenia, relative to controls. This reduction in the slope appeared to be associated with decreased working memory in people with schizophrenia. These findings will now be discussed in turn.

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 (see Graham et al., 2015 for an in-depth examination of this effect). We hypothesised that this may be due to a contraction of the size of a temporal window of associability specific to actions, as a consequence of developmental changes and sensorimotor learning associated with ageing. The current study, conducted on the same sample in which we demonstrated the effect of age on intentional binding, 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.

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. As such, unlike healthy controls, it appeared the estimation of intervals in people with schizophrenia did not follow Weber's Law. 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; 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.

4.3 The role of dopamine in psychosis-like experiences, schizophrenia and time perception

These findings in people with schizophrenia detailed above lead to an apparent contradiction. In a previous study (Graham et al., 2015), we examined the effect of psychosis-like experiences (PLE) on time perception. PLE are 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, Bijl, Vollebergh, & Van Os, 2003; Kendler, Gallagher, Abelson, & Kessler, 1996; Meehl, 1962; Venables, Wilkins, Mitchell, & Raine, 1990). We found PLE 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 the 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 (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, Lee, Chau-Wong, & Wong, 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; Lee et al., 2009), as would be expected if dopamine-blockade were responsible for the changes seen in time perception.

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 (Lee et al., 2009; Roy et al., 2012). The relationship of working memory to time perception is described in the pacemaker-accumulator model of temporal processing for intervals in the subsecond range (Creelman, 1962; Rammsayer, 1990, 1993, 1999; Treisman, 1963). Of importance for this study, this model proposes that an internal pacemaker produces units of time, which are sent to an accumulator. The units of time are stored in an accumulator, where the number of units stored in the accumulator represent the length of the interval i.e. more time units represent a longer interval. A representation of the contents of the accumulator can then be transferred into working memory for use in interval comparisons and judgements, although some models combine the accumulator/working memory stages (Gibbon & Church, 1982; Wearden, 1999). If working memory deficits of schizophrenia affect the ability of the accumulator to store time units or cause a degradation of the interval representation in working memory, less time units will be accumulated in a given period and so an interval will be perceived to be shorter. In order for people with schizophrenia to perceive events in the subsecond range as occurring one after another, rather than simultaneously, events then need to occur further apart in time. It has been proposed previously that such an alteration of time perception may lead to awareness of a movement occurring before the intention to act, the opposite experience of self-generated actions (Spence, 1996), or that a reduced perceived interval between internal and external events may lead to an excessive association of unrelated events (Franck et al., 2005; Haggard et al., 2003).

It should be noted that 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 of subsecond intervals and explicit interval judgements are dominated by changes in the accumulator/working memory stage, not internal pacemaker changes, in schizophrenia.

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 greater 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 $\pm$ SD: Controls = 256 ± 236 ms, Pass. - = 307 ± 277 ms, Pass. + = 221 ± 227 ms) and the slope (mean $\pm$ 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.

4.6 Alternative explanations and possible confounds regarding modulation of time perception in people with schizophrenia

There were no significant differences in the interval estimations between movement conditions reported by people with passivity symptoms, while people with schizophrenia without passivity symptoms reported intervals in the Active and Other conditions to be significantly longer than intervals in the Passive condition. These findings stand in contrast to the increased intentional binding in people with schizophrenia, undifferentiated by symptom profile and using the Libet clock method, that has been observed in previous studies (Franck et al., 2005; Haggard et al., 2003; Voss et al., 2010). Given the discrepancy with the literature and the current study, a critical examination of the factors that may have contributed to the current findings is warranted and will now be discussed.

The first issue to come into consideration is the different methodologies used in studies of intentional binding in people with schizophrenia previously and the current study. The Libet clock method requires participants to judge the time of the key press or tone on separate trials by reference to a rotating hand on a clock (Libet et al., 1983). The interval is not directly judged but inferred from the shift in the perceived time from when the key press/tone actually occurred (Haggard et al., 2002). Subsequently, participants must concentrate on the action or its consequence, but not both, and are required to divide their attention between the event and the clock. The interval estimation procedure allows participants to focus on both the action and the tone and provides a direct estimation of the interval. A potential confound of the Libet method is that, after a voluntary movement, even though people may perceive the action as occurring later and/or the tone occurring earlier, it does not necessarily imply that the interval between two events is perceived as shorter. An alternative explanation for the current findings in people with schizophrenia is that there is a dissociation in perception and timing such that there is a perceptual shift in the keypress and tone but no corresponding shift in the perception of the length of the interval. Given the wide ranging ranges in timing and time perception in people with schizophrenia (Waters, 2013), such a dissociation is feasible. However, the perceptual shift after voluntary movements demonstrated by the Libet clock method corresponds closely to the findings using the interval estimation procedure in undergraduate student samples of interval estimations being reduced after active movements (Cravo et al., 2009; Ebert & Wegner, 2010; Engbert et al., 2008; Moore, Wegner, & Haggard, 2009; Wenke & Haggard, 2009). As the current controls also differ from the previous literature and without corresponding Libet clock data from the current sample of people with schizophrenia, it is not possible to exclude the possibility of a dissociation between perception and timing in people with schizophrenia.

An important methodological consideration concerns the differences in when participants judged the interval to occur. All participants were explicitly instructed to estimate the time between the keypress and the sound, not from the initiation of movement. However, it is possible that some individuals based their judgements on the initiation of movement or on the awareness of the intention to act. By itself, this is unlikely to affect the current results, apart from being a source of variance in interval estimates. This issue may be amplified if there are systematic biases in the timing of movement initiation and the key press between the movement conditions or participant groups. Given the movement in the Passive condition was an induced one, the timing in this condition may have been different from the voluntary

movements of the Active and Other conditions. Controls, however, did not report a significant difference in interval estimations in the Passive and Other conditions so it is unlikely that timing of the key press between conditions is an issue, at least in this group. Concerning the differences amongst groups, it has been reported previously that people with schizophrenia produced a longer contact with the surface of a target object while carrying out a series of tapping movements (Delevoeye-Turrell, Giersch, Wing, & Danion, 2007). If this issue affected the current sample of people with schizophrenia and there were participants in this group who estimated the interval from the movement initiation, it would be expected that more time would elapse between movement initiation and the subsequent tone. A subsequent prediction would be that people with schizophrenia would report the intervals to be longer than controls and this effect would be present at all intervals. The current study demonstrated that people with schizophrenia perceived the interval to be shorter, not longer, with increasing interval length. For this reason, it is unlikely that this issue is an alternative explanation for the current findings.

As described in section 3.1, Brown-Forsythe tests on the variance of interval estimations demonstrated that the variance differed across both groups and intervals, being higher in the Pass. – and Pass. + groups and increasing with longer intervals. It may be that the current findings are better explained as an increase in the variance of interval estimates causing a decrease in interval discriminability. This would in turn decrease the slope of the perceived interval and result in the modulatory effect of actions on time perception to be “washed out” in Pass. +, rather than a true absence of modulation of time perception. However, this explanation is unlikely for several reasons. First, the interaction between group and interval, with the appropriate variance structure, was significant in the linear mixed-effects model. This indicates the decrease in the perceived interval in people with schizophrenia was resistant to the increased variability in interval estimates. Second, if increased estimate variance prevents discrimination of the length of the interval between movement conditions, it would be expected that Pass. + would also display the highest variance in estimates. As seen in Table 2, this was not the case as the highest interval estimate variance was observed in Pass. -. Finally, in addition to demonstrating the highest observed variance in interval estimates, the slope of the perceived interval of Pass. – was not significantly different from that of Pass. +. Given these characteristics, it would also be expected that Pass. – would not display significant differences in interval estimates between movement conditions. That the Pass. – group reported a difference in the perceived interval between movement conditions (albeit in an unexpected direction), is further evidence that increased interval estimation variance did not affect the discrimination of intervals between movement conditions in people with schizophrenia.

We proposed in section 4.4 that the decrease in the perceived length of the interval with increasing interval length reported by people with schizophrenia is due to impaired working memory affecting the accumulator stage of temporal processing. It is also likely that the increase in variance in interval estimates described above is due to impaired working memory. This is because inter- and within-subject differences in the rate of degradation of accumulated time units in the accumulator increase variability in interval estimations (Gibbon & Church, 1982). One implication of this proposal, however, is that the cognitive demands of the task may increase with increasing interval length, particularly for people with schizophrenia. This then may reduce the ability of people with schizophrenia to discriminate intervals between movement conditions, particularly at longer intervals. However, as described in the previous paragraph, it is unlikely that increased variance of interval estimations affected the experience of the interval between movement conditions. Indeed, that Pass. – reported differential responses to the movement conditions, despite also having lower

digit span scores than healthy controls, is further evidence that impaired working memory did not affect the modulation of time perception by actions.

Another possible confound is that the differences seen in action-triggered modulation of time perception between the two groups of people with schizophrenia is a reflection of differences in clinical state, particularly in current symptomatology, rather than the changes specific to passivity symptoms. That the SAPS composite score was significantly higher in Pass. + could be indication of a more chronic, severe illness in this group, or a reflection of a smaller period of time since the last psychotic episode. However, if this were the case, it would be expected that there would be other clinical or neuropsychological characteristics indicative of a worsened clinical state and/or a significant interaction of the SAPS composite score with one or more of the other independent variables would have been present. As has been noted already, no other such characteristics were significantly different between Pass. + and Pass. -. Also, as noted in section 3.1, the SAPS and SANS composite scores were originally included in the analysis but no significant interactions were found. It is therefore unlikely that the differences in time perception observed between the Pass. - and Pass. + groups are due to the clinical state of the participants of each group, and are more likely due to the presence or absence of passivity symptoms.

4.7 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; Fournieret, Franck, Slachevsky, & Jeannerod, 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, the significant age by condition interaction in the analysis of the 200 ms interval data confirmed that the presence of perceptual repulsion in Pass. - is also linked to increasing age in this sample. Indeed, the mean age of the participants in the Pass. - group (mean = 44.6) was notably older compared to two of the previous three studies of intentional 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).

4.8 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 and Other movement conditions or an absence of time modulation triggered by intentional processes in the Active condition. One difficulty of interpreting this result is that people with schizophrenia have wide-ranging deficits in the planning, timing and execution of voluntary movements (Carnahan, Aguilar, Malla, & Norman, 1997; Danckert, Saoud, & Maruff, 2004; Delevoeye-Turrell et al., 2007; Grootens et al., 2009; Knoblich, Stottmeister, & Kircher, 2004; Maruff et al., 2003). As such, it is difficult to determine casual relationships. That is, if actions do not trigger the correct post-action processes in people with passivity symptoms because of impaired internal timing processes or because the internal timing processes are not modulated because of other issues with intentional motor signals such as a failure of sensorimotor prediction.

Despite these difficulties, there are several lines of evidence that elucidate the possible mechanism behind the absence of modulation of time perception by voluntary actions in people with passivity symptoms. 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, Wenke, Rothwell, & Haggard, 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. 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 failure of such processes has been observed previously in people with passivity symptoms (Blakemore et al., 2000; Lindner, Thier, Kircher, Haarmeier, & Leube, 2005; Synofzik, Thier, Leube, Schlotterbeck, & Lindner, 2010). Additionally, the degree of imprecision of predictive processes is positively correlated with the presence of passivity symptoms (Synofzik, Thier, Leube, Schlotterbeck, & Lindner, 2010; Voss et al., 2010). 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.

4.9 Functional significance of findings in passivity symptoms

As we speculated in the previous paragraph, impaired predictive processes in people with passivity symptoms may fail to modulate the appropriate timing processes as in healthy controls. 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 not differentiated by 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 (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. The first step relates to a contemporary cue integration of agency (Moore & Fletcher, 2012; Synofzik, Vosgerau, & Lindner, 2009; Synofzik, Vosgerau, & Voss, 2013) where the contribution of agency cues to the final experience of agency is determined by the reliability of each cue (Moore & Fletcher, 2012). If a particular agency cue is absent or unreliable, this can be compensated for by increasing the contribution of the other cues, such as visual feedback, the observation of other agents, and other social/contextual cues (David, Newen, & Vogeley, 2008; Synofzik, Vosgerau, & Newen, 2008). In the case of passivity symptoms, the unreliable and imprecise internal sensorimotor prediction leads to a reliance on external agency cues and possibly confusion regarding whether actions have been generated by the self or an other (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), the impaired construction of the chronological order of efferent and afferent signals - 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.

4.10 Limitations

One limitation is the relatively smaller size of the Pass. + group compared to the Pass. - and Control groups. Particularly when combined with the large observed variance, the lower sample size may have obscured some treatment contrasts between groups. Another weakness of the study is the presumption that, because it was triggered by an intentional movement, the perceptual repulsion observed in controls and Pass. - is a marker of agency in these groups. It may well be the case that the controls and Pass. - did not feel agency over the triggering of the tone. As we did not assess the experience of explicit agency over the sensory outcome of the action, it is difficult to confirm that these people did in fact experience agency over the tone; further studies of intentional binding should include a measure of explicit agency to examine this possibility. Finally, it is plausible that the removal of the cross on the screen (a sensory event that is temporally contiguous and predictable) between the action and the tone, (a subsequent but temporally unpredictable sensory event) weakens the association between the action and its sensory consequence. This may have resulted in the presence of perceptual repulsion in Controls and Pass. -. However, care was taken to ensure that participants were focusing on their hand and not the screen, so it is unlikely that this occurred for many participants.

4.11 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 modulation of time perception by actions, suggesting 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. The current results challenge our understanding of the relationship between actions and time perception in people with schizophrenia, both with and without passivity symptoms. The causal relationships between motor planning, motor prediction, intentional signals and time perception in schizophrenia may be more complicated than previously assumed.

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Figure 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 $\pm$ SEM. Contrasts for post-hoc comparisons are reported in text.

Figure 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 $\pm$ SEM. ^ $0.05 < p < 0.1$, * $p < 0.05$.

Figure 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: $5 \leq$ ("Low", $n = 13$), $5 < \text{BDS} < 8$ ("Middle", $n = 17$), ≥ 8 ("High", $n = 9$). Data shown are mean $\pm$ SEM.

Figure 4. Effect of age on an interval estimation task in which participants judged the time between the active pressing of a button (“Active”), the passively-induced pressing of a button (“Passive”) or the observation of another agent pressing a button (“Other”) and a tone played through headphones 200 ms after the initiation of the button press. To aid in data presentation, subjects were binned into four age groups: 21 – 30 years of age, 31 – 40 years of age, 41 – 50 years of age and 51 – 60 years of age. Data shown are mean $\pm$ SEM.

Table 1. Demographic and neuropsychological information of participants

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

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 Guidelines (Taylor, Paton, & Kapur, 2009) and Psychotropic Drug Guide (Bazire, 2009).

Table 2. Standard deviations of interval estimations for 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. +). Homogeneity of variance was assessed at each interval using the Brown-Forsythe test.

Interval (ms)	Controls	Pass. -	Pass. +	Brown-Forsythe test
200	118	238	143	$F(2, 3521) = 125, p < 0.0001$
400	202	255	217	$F(2, 3532) = 26.3, p < 0.0001$
600	279	306	270	$F(2, 3524) = 14.2, p < 0.0001$