Slowing and Stopping in Schizophrenia

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Declaration

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4. The work in this thesis was carried out under the supervision of Professor Andrew Heathcote, Australian Professorial Fellow at the School of Psychology, the University of Newcastle; and Emeritus Professor Patricia Michie at the School of Psychology, the University of Newcastle.

5. The conduct of this research was approved by the Hunter New England Human Research Ethics Committee and the University of Newcastle Human Research Ethics Committee (approval number 12/07/18/4.05).

Signed:…………………………………….. Date:…………………….
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Structured Abstract

**Background:** Individuals with Schizophrenia have been described to have extensive cognitive impairments that span across several domains and can significantly impact functional outcomes and quality of life. Slowing in reaction time paradigms has been consistently documented in Schizophrenia such as in simple and choice reaction time tasks. In addition to slowing, the performance by individuals with Schizophrenia in choice reaction time tasks has also been documented to be more variable and error prone relatively to healthy participants. Executive functioning deficits in Schizophrenia are profound and as a result, response inhibition difficulties have been reported across various paradigms. Model-based analysis have not yet been conducted in regards to choice reaction time performance in Schizophrenia, and this method has the potential of uncovering further underlying cognitive processes in decision-making. **Method:** A meta-analysis was conducted to extend and expand the investigations by Schatz (1999) to include information of accuracy and standard deviation as well as reaction time, and performance of participants with Schizophrenia and health control groups was compared. An experiment was also conducted that took place across two sessions on separate days. Nineteen participants with Schizophrenia or Schizoaffective disorder, as well as control participants matched by age and gender were recruited. In the first session, participants completed a choice reaction task, completed measures of working memory and premorbid intelligence, and participants with Schizophrenia also completed a clinical interview. The second session included a stop-signal task, data from which was not analysed further in the research manuscript due to the time-frame limitations of the project. The data from the choice reaction time task were fit by two cognitive models of choice processes: the Drift-Diffusion model (DDM, Ratcliff & McKoon, 2008) and the Linear Ballistic Accumulator model (LBA, Brown & Heathcote, 2008). **Results:** The meta-analysis revealed a consistent pattern of control groups performing faster and more accurately relative to
participants with Schizophrenia in choice reaction time tasks. Reaction time and accuracy comparisons from the experiment indicated that participants with Schizophrenia were slower and less accurate in their responding, however this finding was not significant. Model-based analyses revealed that the LBA fit the data better than the DDM and produced a greater number of significant results, which are described in further detail. Sequential effects were found in the Schizophrenia group and model-based analyses further confirmed a bias towards participants with Schizophrenia repeating the immediately past response. A positive correlation was found between mean reaction time and negative symptoms in the Schizophrenia group. Furthermore, the combined effects of the threshold and rate parameters in the model-based analysis suggested a differential response strategy occurring in the group of participants with Schizophrenia relative to controls. Conclusions: The findings in the present study echo previous reports of slower and less accurate performance in Schizophrenia in choice reaction time tasks. A more in-depth discussion is provided regarding the possible interpretations of the threshold and rate parameter results. Relevant research findings regarding perseveration, flexibility in responding, as well as motion perception deficits in Schizophrenia are described and integrated with the results obtained. Finally, the strengths and limitations of the present study are highlighted and recommendations for future research and the potential implications of the present study are proposed.
1. A CRITICAL REVIEW OF THE LITERATURE

1.1 Schizophrenia

1.1.1 Description of the illness

Schizophrenia (Sz) is a severe chronic illness characterized by disturbances in cognition, behaviour, emotion, and perception (American Psychiatric Association [APA], 2013; Frangou & Kington, 2004). Clinical symptoms of Sz include hallucinations, delusions, disorganised speech and behaviour, and negative symptoms, such as poverty of thought and speech, social withdrawal, blunted and flat effect, and a loss of motivation and experience of pleasure (APA, 2013). The World Health Organization ranks Sz as one of the top six causes of disability, with approximately 25 million individuals suffering from the disorder worldwide (World Health Organization, 2003). The disorder has substantial associated costs; in Australia alone it is estimated to cost $1.44 billion per annum, mostly due to direct mental health care costs and lost productivity (Carr, Neil, Halpin, Holmes, & Lewin, 2003). Hospitalisation is one of the highest costs and accounts for 80% of mental health care expenditure for individuals with Sz (Carr et al., 2003). Risks of mortality are at least twice as high for people with Sz than for people in the general population, with the leading causes of death being suicide, accidents, and cardiovascular disease (Frangou & Kington, 2004; SANE Australia, 2002).

1.1.2 Cognitive deficits in Schizophrenia

In the latest edition of the Diagnostic and Statistical Manual of Mental Disorders 5 (DSM-5; APA, 2013) cognitive deficits were not included amongst the characteristic symptoms in Criterion A, despite careful consideration given to this possibility (Barch et al.,
2013; Tandon et al., 2013). Thus, for the purposes of the current review, cognitive deficits will be referred to as separate from the clinical symptoms of Sz. Cognitive impairments have been described as a core feature of Sz and not simply as a result of its associated clinical symptoms or medication effects (Gold & Harvey, 1993; Green, Kern, Braff, & Mintz, 2000; Joyce & Huddy, 2004; Sharma & Harvey, 2000). A decline in cognitive functioning often precedes the emergence of psychotic symptoms and has been described as a potential disease marker for the disorder (Caspi et al., 2003; Eastvold, Heaton, & Cadenhead, 2007). The acute phase of the illness, where clinical symptoms are often at their most severe, is usually associated with substantial cognitive impairment (Bonner-Jackson, Grossman, Harrow, & Rosen, 2010) and an untreated psychosis can have further devastating effects on cognition (Amminger, Edwards, Brewer, Harrigan, & McGorry, 2002; Lappin et al., 2007).

Cognitive impairments in Sz are found across several domains and occur in almost all people with Sz (Keefe & Harvey, 2012). Numerous research studies have investigated the nature of impaired cognition in Sz and results are varied depending on the neurocognitive testing battery employed and how the findings are conceptualised (Keefe & Harvey, 2012). The National Institute of Mental Health (NIMH) has established the Measurement and Treatment Research to Improve Cognition in Sz (MATRICS) project in order to identify the main cognitive deficits observed in Sz and to develop a neurocognitive test battery to assess these deficits (Green et al., 2004). The most significant deficit domains in Sz were identified as working memory, attention/vigilance, verbal learning and memory, visual learning and memory, reasoning and problem solving, speed of processing, and social cognition. Numerous other studies have documented the widespread and multifactorial nature of cognitive deficits in Sz spanning across various cognitive domains (Dickinson, Ragland, Gold, & Gur, 2008; Heinrichs & Zakzanis, 1998; Keefe & Harvey, 2012; Nuechterlein et al., 2004; Stefanopoulou et al., 2009).
1.1.3 Impact on functional outcomes

Cognitive impairment is a strong predictor of functional outcomes and quality of life over and above psychotic symptoms of Sz (Green, 1996; Morrens, Hulstijn, & Sabbe, 2007; Nuechterlein et al., 2011; Palmer, Dawes, & Heaton, 2009; Velligan & Bow-Thomas, 1999). For individuals with Sz, cognitive impairments can have devastating effects on the ability to engage in employment, social interactions, self-care, and community activities, and as a result quality of life can be greatly compromised (Aubin, Stip, Gelin, Ranville, & Chapparo, 2009; Brekke, Levin, Wolkon, Sobel, & Slade, 1993; Green, 1996; Milev, Ho, Arndt, & Adreasen, 2005).

Further investigation into the cognitive impairments in Sz is warranted, considering the profound effects that they have on the quality of life of those affected. Gaining further insights into these deficits can enable the development of targeted interventions, provide further specificity in terms of the cognitive domains affected, and also reach a better understanding of the daily life struggles experienced by individuals with Sz.

1.1.4 The effects of antipsychotic medication on cognitive functioning

Conventional neuroleptics can be efficacious in reducing positive symptoms of Sz, however, they have little effect on improving cognitive impairments (Hegarty, Baldessarini, & Tohen, 1994; Keefe, Silva, Perkins, & Lieberman, 1999). Small to moderate improvements in neurocognitive measures have been associated with atypical anti-psychotic treatment in various domains of cognition (Cuesta, Peralta, & Zarzuela, 2001; Davidson et al., 2009; Harvey, Green, McGurk, & Meltzer, 2003; Keefe et al., 2007; Meltzer & McGurk, 1999; Mishara & Goldberg, 2004; Weiss, Bilder, & Fleischhacker, 2002). However, this evidence needs to be interpreted with caution given the methodological weaknesses commonly found across research studies in this area, such as inadequate treatment duration, small sample sizes, a lack of double-blind experimental designs, and inappropriately selected neurocognitive
measures (Meltzer & McGurk, 1999; Purdon, 1999; Weiss et al., 2002). This methodological variability is particularly evident in earlier studies investigating conventional neuroleptics (Harvey & Keefe, 2001). This adds a degree of complexity in making comparisons between studies due to the variability in methodology (Harvey et al., 2003; Keefe et al., 1999). Thus, there are presently no approved pharmacological treatments available for cognitive impairments in Sz (Keefe et al., 2007).

1.1.5 The focus of the current literature review

The current literature review will focus specifically on response slowing and response inhibition in the context of fast decision-making in Sz. The aim is to explore how people with Sz make simple decisions, particularly in conditions where speed is emphasized, as well as how accurate and variable their performance is. An important aspect of quick decision-making is the ability to withhold a response that is no longer required or is irrelevant, so another aim of the present review will be to investigate response inhibition in individuals with Sz, particularly in studies utilizing the stop-signal task, which will be explained in further detail in subsequent sections. In light of the scope of the current thesis, the focus is centred on studies specifically looking at choice reaction time (CRT) paradigms, where a participant is required to make a quick choice between two or more options. This kind of paradigm can facilitate investigation into the specific mechanisms underlying response selection, as it is relatively free from strategies and higher order judgements that are often required in more complex decision making tasks (Lee, 2006). A brief overview of earlier studies involving simple reaction time (RT) measures will be provided initially to set a historical context for the current directions in Sz CRT research. The speed, accuracy and variability of performance in CRT tasks by participants with Sz will also be investigated and relevant literature will be reviewed. Finally, impairments in response inhibition in Sz will
also be explored and a review of research specifically utilizing the stop-signal paradigm will be discussed.

1.2 Slowing in Schizophrenia

1.2.1 Slowing of simple reaction time in Schizophrenia

Research into RT differences in Sz was energized in the 1920s and in a review of RT literature published by Wells and Kelley (1922) documented a finding of markedly slower simple RTs in patients with psychosis compared with healthy participants. Huston, Shakow, and Riggs (1937) went on to confirm that individuals with Sz were also slower in responding to auditory and visual stimuli, compared to controls. Huston et al. manipulated the preparatory intervals (PIs) – the time between a warning signal and the RT stimulus – by having regular and irregular series of PIs. Presumably, the participant may use the regular series to their advantage to anticipate when the stimulus arrives and maximize their preparedness for it. Unlike controls, individuals with Sz were slower on all lengths of PIs (ranging from 0.5 to 10 seconds), irrespective of whether they were regular or irregular. They were also unable to improve their RTs in the regular relative to the irregular condition when PIs were longer than 2 seconds. This prompted Huston et al. (1937) to propose that individuals with Sz were unable to maintain the same level of preparation in response to stimuli compared to their healthy counterparts.

Rodnick and Shakow (1940) extended on these findings further and discovered that healthy participants were able to benefit from the regularity of PIs and had faster RTs in the regular condition compared with the irregular presentation of PIs, while the Sz group displayed an opposite effect, i.e., slower RTs in the regular condition relative to the irregular condition. Plotting RT against the length of the PIs separately for the two PI conditions yields two curves. The crossover effect refers to when these two curves intersect, and this was found to occur for participants with Sz usually in the range of long PIs. Rodnick and Shakow (1940)
concluded that the Sz group was less able to maintain a preparatory set for more than a few seconds and that this is a key feature of the disorder. More recent research has documented that the crossover effect could signify a disease marker for individuals at risk of developing Sz (Maier et al., 1994).

In addition to difficulties in maintaining a preparatory set, further evidence indicates that individuals with Sz also performed significantly slower on trials that had a stimulus modality, which differed from the previous trial (Mowrer, 1941). The modality shift procedure involves the presentation of ipsimodal sequences (e.g. tone preceded by a tone) and cross modal sequences (e.g. tone preceded by light), and the difference in RT between these two conditions is referred to as the modality shift effect. Participants with Sz tended to display a more pronounced modality shift effect relative to controls (Sutton, Hakarem, Zubin, & Portnoy, 1961). Preceding events such as PI and modality differences seem to have a more substantial influence on RT in Sz relative to healthy participants (Cancro et al., 1971; Zahn, Rosenthal, & Shakow, 1961; Sutton et al., 1961). Zubin (1975) proposed that the modality shift and cross over effect findings in Sz RT literature suggests that prior events can leave behind facilitatory or inhibitory neuronal traces, and that these traces tend to persist longer in Sz relative to healthy individuals.

More recently, across an extensive variety of simple RT tasks and paradigms that require manual responses, slower simple RTs in Sz relative to healthy individuals have been consistently documented (Cancro, Sutton, Kerr, & Sugerman, 1971; Gale & Holzman, 2000; Maier et al., 1994; Nuechterlein, 1977; Rosofsky, Levin, & Holzman, 1982; Schatz, 1998; Schwartz et al., 1989). Unlike performance in RT tasks requiring manual responses, saccadic RTs have been found to be relatively unimpaired in Sz (Gale & Holzman, 2000; Iacono, Vicente, Tuason, & Johnson, 1981; Levin, Holzman, Rothenberg, & Lipton, 1981: Zahn, Roberts, Schooler, & Cohen, 1998). Increased manual RT latencies have been described as a potential disease marker to identify individuals vulnerable to developing Sz (Bredgaard &
Glenthøj, 2000; Cannon et al., 2000). For example, RT latencies are more pronounced in Sz than in other psychiatric disorders, such as mood disorders (Fleck, Sax, Strakowski, 2001; Hemsley, 1976) and are associated with poorer prognosis and poorer outcomes (Cancro et al., 1971; Nuechterlein, 1977).

1.2.2 The introduction of choice

Unlike the simple RT paradigms, CRT tasks require an additional decision-making element whereby a choice is required between two or more options. The CRT paradigm can help to uncover the stage or stages of information processing that may be impaired in Sz (Neuchterlein, 1977). Given the abundance of research on simple RT slowing in Sz, early researchers began to question whether CRT will be significantly more impaired, given that it introduces further task complexity in the form of a choice. Interestingly, the findings so far have been inconsistent.

An early comparison study found that although Sz participants were slower on both tasks, they were significantly more impaired on the simple RT task than the CRT task relative to controls (Benton, Jentsch, & Wahler, 1959). On the other hand, Karras’ (1967) sample of Sz participants were slower in both tasks relative to controls, however the difference in slowing between the simple RT and the CRT task occurred in an equal proportion to that of controls. More recently, participants with Sz have been shown to have a greater and disproportionate slowing on CRT tasks compared with simple RT tasks, relative to healthy controls (Hintze, Bebenek, Kuhn-Dymecka, Wronska, and Wciorka, 2006; Zahn et al., 1998).

Several studies have utilized RT decomposition-paradigms to shed light on the introduction of choice. For instance, Krieger et al. (2001) compared performance on a simple RT task, a discrimination task (reacting to one stimulus while ignoring another), and a CRT task (responding with a different response to each stimulus). They found that, relative to controls, the inclusion of choice resulted in a disproportionate increase in RT in the
neuroleptic-naïve and long-term medicated participants, but not in those that have received treatment for five weeks. Krieger et al. (2005) found similar results using such a paradigm in their sample of twelve first-episode drug-naïve Sz participants, who were observed to have disproportionately longer RTs with the introduction of choice relative to controls.

In comparison with healthy participants, individuals with Sz respond even slower on a 4-choice relative to a 2-choice CRT task (Pelizzer & Stephane, 2007; Woodward, Duffy, & Karbasforoushan, 2014). According to Hick’s Law (Hick, 1952), increasing the number of choices will increase RT logarithmically, so that an exponential linear slope can be observed as the number of response options is increased. When comparing between groups, if slopes are the same, this suggests that both groups exhibit similar increases in RT as response options are increased. If one group has a steeper slope than the other, this may suggest that the group with the steeper slope may be having a more pronounced exponential increase in RT as response alternatives are increased. Venables (1958) manipulated the number of choices within the task by using up to eight stimulus lights, and hypothesized that as the number of task choices increased, the Sz group would display slower RT than healthy controls. Interestingly, the Sz participants did not produce steeper Hick’s law slopes relative to controls as the number of stimuli used was increased. Scherer (1972) similarly reported that an increase in stimulus complexity did not lead to steeper Hick’s law slopes for the Sz group compared with controls, despite the Sz displaying significantly slower RTs across all complexity conditions.

Hemsley (1976a) conducted a review of studies in this area and argued for the importance of distinguishing varying stimulus and response uncertainty, as well as how compatible the stimulus-response is (e.g. left presented stimulus requiring a response from left side of body). Hemsley (1976a) proposed that the Hick’s law slopes are steeper for participants with Sz only when response uncertainty is varied and the task has low stimulus-response compatibility. In a separate study, Hemsley (1976b) reported that the Sz group were
more affected by increasing response uncertainty compared with depressed participants, and that the increases in stimulus uncertainty did not yield a similar effect. Unfortunately, no healthy comparison group was included in this study. Williams and Hemsley (1986) investigated the effect of increasing task complexity on the performance of a sample of Sz, depressed, and healthy participants on a CRT task. They found that the Sz and depressed participants performed similarly across the conditions, but when grouped together, their mean RT was significantly higher than controls, and their performance became progressively slower as task complexity increased. Similarly, Marshall (1973) found RT in Sz was affected by increasing both stimulus and response uncertainty, but the latter led to the largest increases in RT.

It has been suggested that a key deficit in Sz is the difficulty of translating perception into action at the decision stage of information processing (Hemsley, 1976b; Krieger et al., 2001), which makes sense given the aforementioned findings regarding slower performance in Sz once choice is introduced or response complexity is increased. In a cognitive model of processing speed, Pashler (1994) has conceptualised information processing to be comprised of three stages: perceptual analysis, response selection, and response production. In accord with this proposition, impaired performance on CRT tasks has been linked to altered connectivity between brain regions involved in response selection (Krieger et al. 2001; 2005; Pellizer & Stephane, 2007). Electrophysiological investigations have also indicated that lateralized readiness potential measures (LRP), which are considered to represent stimulus-response translation, are abnormal in Sz (Kappenman et al., 2012; Luck et al., 2009). Woodward et al. (2009) observed correlations between performance on CRT tasks and unique patterns of connectivity between multiple brain regions in Sz participants and their healthy relatives, compared to healthy controls, indicating a genetic liability for response selection deficits.
1.2.3. A review of choice reaction time literature in Schizophrenia

In this section, the aim is to present a review of the studies where CRT paradigms have been utilized and discuss some of the general findings in the areas examined. Due to the sheer magnitude of research involving CRT paradigms, key research articles will be grouped in terms of the general cognitive domains investigated.

Attention is an area of study that contains a wealth of research employing CRT paradigms. Sustained and selective attention is considered to be of the two most studied areas in Sz literature (Chan, Chen, Cheung, Chen, & Cheung, 2004) with some of the earliest explanations for slowing in simple RT in Sz have been related to the inability to engage attention or preparatory “set” (Rodnick & Shakow, 1940). CRT tasks in the study of attention typically involve the use of various distractors and flankers (e.g., Kopp, Mattler, & Rist, 1994) as well as investigating the effects of diverse cuing conditions and the position of stimuli (e.g., Daban et al., 2004; Frecska, Symer, White, Piscani, & Kulcsar, 2004). Several studies also used alerting or orienting trials to see whether this would increase attention (e.g. Amado et al., 2011; Chirio et al., 2010), while others investigated the shifting of attention from a global to local focus and vice versa (Coleman et al. 2009).

In CRT tasks targeting selective attention, participants with Sz were found to have significantly slower RTs and performed less accurately relative to healthy controls (Chan et al., 2004; Jones, Hemsley, & Gray, 1991; Urbanek et al., 2009;). Other studies described slower RT’s in the Sz samples relative to controls on CRT tasks but do not actually report accuracy data (Chirio et al., 2010; Coleman et al., 2009; Daban et al., 2004; Wood & Cook, 1979) or report that the Sz participants performed as accurately as controls but also do not publish accuracy scores (Amado et al., 2011). Interestingly, a more common finding in the attention literature is that Sz participants tend to be slower in CRT tasks, but perform as accurately as their healthy counterparts (Amado et al., 2011; Hirt & Pithers, 1990; Kopp et al., 1994; Frecska et al., 2004).
Similar patterns of results were found in studies of semantic processing in Sz. Some reports were that participants with Sz were slower in their RT on the various lexical-decision paradigms and also less accurate compared with healthy control participants (Fuentes & Santiago, 1999; Hokama, Hiramatsu, Wang, O’Donnell, & Ogura, 2003; Safadi, Lichtenstein-Vidne, Dobrusin, & Henik, 2013). However, a more consistent finding was that even if Sz participants had slower responding, their accuracy was in fact comparable with healthy controls (Baving, Wagner, Cohen, & Rockstroh, 2001; Froud, Titone, Marantz, & Levy, 2010; Minzenberg, Poole, Vinogradov, Shenaut, & Ober, 2003, Nestor et al., 2006; Passerieux, Hardy-Bayle, & Widlocher, 1995; Prochwicz & Zuchowics, 2013).

Research into the working memory (WM) capabilities of individuals with Sz uses CRT tasks that often involve manipulations of WM load. For instance, the n-back paradigm is a commonly used CRT task in the study of WM, which involves participants judging whether or not the target stimulus matches the stimulus on the N-back trial. Participants with Sz were found to be significantly slower in their RT and more error-prone than healthy participants on the n-back paradigm (Keefe, 2000). Krieger et al. (2005) utilized a RT decomposition approach and found that Sz participants performed with similar accuracy as controls on all RT tasks aside from the one that required a WM memory load. In this study, Sz participants were also found to have slower RTs than controls on all tasks, but unlike controls, they showed disproportional slowing with the introduction of a WM requirement. The consistent finding in this area of research is that participants with Sz seem to be particularly impaired as evidenced by higher error rates and slower RT than controls, when WM load is imposed or increased or when they are required to select information from WM during CRT tasks (Koh, Scoz, & Peterson, 1977; Manoach et al., 1999; Quee, Eling, van der Heijden, & Hildebrandt, 2011; Smith, Eich, Cebenoyan, & Malapani, 2011).

The Stroop paradigm is frequently used in the research of Sz cognitive deficits and can be conceptualised as a CRT task as it involves making a choice between two responses,
i.e., identifying the colour or identifying the name of written stimulus. It is considered a test of cognitive inhibition, as the dominant process is to read the word and thus the participants are required to inhibit the reading process in favour of naming the ink colour (Cohen, Dunbar, & McClelland, 1990; Friedman & Miyake, 2004). There are various conditions such as congruent (e.g. “red” written in red ink), neutral (e.g. “XXXX” printed in blue) and incongruent (e.g. the word “blue” printed in red). Stroop facilitation occurs if the participant is faster in the congruent compared with the neutral condition, and Stroop interference refers to faster RT in the neutral relative to the incongruent condition (Barch, Carter, & Cohen, 2004). For the purposes of this review, only studies utilizing the single-trial Stroop paradigm were considered, where words were presented one at a time, as opposed to the more traditional card version, which presents numerous Stroop stimuli concurrently.

Studies using the Stroop task have revealed a consistent pattern of results where participants with Sz indicate a slower and less accurate performance with significantly increased Stroop facilitation but no difference in interference relative to healthy controls (Barch et al., 1999; Barch, Carter, & Cohen, 2004; Barch, Carter, Hachten, Usher, & Cohen, 1999; Carter, Robertson, & Nordahl, 1992; Chen, Wong, Chen, & Au, 2001; Perlstein, Carter, Barch, & Baird, 1998). Carter, Robertson, Nordahl, O-Shora-Celaya, and Chaederjian reviewed the results of Carter et al. (1992) and explained that illness subtype accounted for the effect found, such that the group with the undifferentiated subtype of Sz had an increased facilitation effect, whereas the paranoid subtype showed normal amounts of facilitation but also increased interference. Others suggest that Sz participants are slower on this task but perform as accurately as controls (Fassbender, Scangos, Lesh, & Carter, 2014).

CRT tasks have also been used in the study of emotion processing. Relative to controls, individuals with Sz were found to be slower in discriminating pictures of bodies (Bauer et al., 2011), and slower but as accurate as controls in discriminating emotions (Burch, 1980) and face recognition (Lee, Kwon, Shun, Lee, & Park, 2007). Furthermore, they
were less accurate but as fast as controls at emotion and face recognition (Doop & Park, 2009). Some authors report highly accurate performance across groups in emotion processing (Burch, 1980; Lee et al., 2007).

Other CRT tasks with generally high accuracy performance across groups were found in studies of executive functioning and response inhibition utilizing paradigms such as the stop-signal paradigm. The stop-signal task will be discussed in further detail in a subsequent section, however, to summarise, it contains an initial component named the “go-task” which is a CRT task requiring choices to be made between two alternatives (e.g. judging the direction of an arrow as “left” or “right”) without an inhibition component. Reviewing the performance of Sz participants on the go-task of these studies yields some contradictory results with reports that Sz participants are slower and less accurate (Badcock, Michie, Johnson, & Combrinck, 2002; Hughes, Fulham, Johnson, & Michie, 2012), and others finding performance to be similar to controls but significantly more error prone (Bellgrove et al., 2005; Nolan, D’Angelo, & Hoptman, 2011).

This brief review highlights that the paradigms that were commonly employed in the studies reviewed were often CRT tasks that involved very simple appraisals of stimuli (e.g. choosing between “X’s” and “O’s” by making a key-press) of which tend to produce few errors. Unlike the studies using more complex WM paradigms or stimuli that requires processing of emotions or faces, accuracy rates for simple CRTs were often fairly high across groups in most studies (typically ranging between 90-99%), indicating a ceiling effect. This suggests that the tasks employed were low in difficulty and were not designed to generate many errors, which can make it more difficult to detect group differences in performance. A frequent finding in the present review of studies was that accuracy rates were not actually reported (e.g. Laurent, Kostova, & Passerieux, 2010; Ngan & Liddle, 2000, Ober, Vinogradov, Y Shenaut, 1995; Vinogradov, Poole, Willis-Shore, Ober, & Shenaut, 1998) which prevents the exploration of any potential speed-accuracy trade-offs that may be
occurring in the decision-making process. Some excluded their participants’ data from further analyses if their accuracy fell below a pre-determined level (e.g., Ober, Vinogradov, & Shenaut, 1995) while others had their participants conduct pre-training aimed at improving accuracy (e.g., Woodward, Duffy, & Karbasforoushan, 2014).

Although this is not an exhaustive review of all available studies using CRT tasks, it provides a general idea of the types of paradigms used and what the pattern of findings tends to be. A consistent finding was that participants with Sz were slower than healthy controls on a variety of RT paradigms. Although accuracy is not always reported or analysed in great detail, the general observation was that participants with Sz seem to be more error prone in their performance. However some contradictory findings exist in that regard, usually in studies where CRT tasks lead to very high accuracy across groups leading to a ceiling effect. These inconsistencies raise the importance of conducting a more systematic review of the findings in these studies, such as in the form of a meta-analysis. This method can provide the opportunity to evaluate and statistically combine the results of comparable studies and provide greater insights into patterns of findings in the literature (Fagard, Staessen, & Thijs, 1996). This is one of the aims of the present study and will be discussed in further detail in a subsequent section.

1.2.4 Variability in choice reaction time performance

In addition to exhibiting differences in their RT and accuracy compared with healthy controls, a more recent finding is that participants with Sz are also more variable in making simple decisions. Across a number of studies, participants with Sz have been found to display significantly higher intra-individual variability (IIV) relative to their healthy counterparts when completing CRT tasks (Badcock et al., 2002; Kaiser et al., 2008; Kim et al., 2009; Rentrop et al., 2010; Vinogradov et al., 1998). IIV has been speculated to reflect the stability of cognitive processing (Kaiser et al., 2008), and Rentrop et al. (2010) proposed that
increases in IIV in Sz could suggest unstable information processing, due to amplified noise in the fronto-cerebellar circuits. The notion of increased noise is supported by functional magnetic resonance imaging data (fMRI) and electrophysiological data of frontal cortical networks (Winterer & Weinberger, 2004; Winterer et al. 2006). Andreasen, Paradiso, and O’Leary (1998) proposed that a disconnection occurs in the fronto-thalamic-cerebellar circuits in Sz, which leads to the deregulation and instability of thought and action processes.

Individuals with Sz display a broad range of cognitive deficits making it difficult to delineate the effect of general cognitive impairments from IIV (Rentrop et al., 2010). In order to investigate whether IIV in RT is a unique deficit in Sz, research has focused on participants with Sz who have relatively preserved cognitive functions (Heinrichs et al., 2008). Rentrop et al. (2010) investigated performance on a CRT task with a group of twenty-eight participants with Sz. These participants were defined as high functioning as they did not significantly differ on measures of premorbid intelligence or cognitive functioning from the healthy control group, and they were also participating in a demanding professional training program. Rentrop et al. (2010) found that participants with Sz did not differ significantly in terms of accuracy or RT as compared with the control group, but they did display significantly higher IIV. They found that the increase in IIV was due to participants with Sz having a greater proportion of abnormally slow responses, which caused a right skewed-distribution in RT. These slow responses correlated significantly with lower scores on a measure of working capability named The Osnabruck Work Capabilities Profile (Wield, Uhlhorn, & Jons, 2004). Rentrop et al. (2010) proposed that slower RTs observed in Sz could be due to the instability of information processing in the response system rather than general slowing.

Kieffaber et al. (2006) have argued that studies often focus on mean RT and standard deviation (SD) to investigate IIV and that this puts undue focus on central tendency. This approach may disregard the impact that the experimental conditions may have on several
aspects of the RT distribution and Kieffaber et al. (2006) suggests the utility of ex-Gussian modelling approaches to assist in uncovering further insights into IIV in Sz. The ex-Gaussian representation of RT variability is comprised of a normal distribution with a right-sided exponential “tail” (Fassbender, Scangos, Lesh, & Carter, 2014). The exponential tail can capture some of the longer RTs, which ordinarily skew the standard mean RT measure and make it appear larger. This approach yields the parameters tau, mu, and sigma. Tau refers to the mean and SD of the exponential component of the distribution. In the normal component of the distribution, Mu refers to the mean and sigma the SD. The high tau parameter has been conceptualised to represent trials on which lapses in proactive control and in task engagement have occurred (Fassbender et al., 2014). Proactive control has been described as the ability to maintain task rules and goals and influence attention in order to maintain preparedness during a cognitive task (Fassbender et al. (2014) and has been found to be particularly impaired in Sz (Edwards, Barch, & Braver, 2010; Lesh et al., 2013; Leth-Steensen, Elbaz, & Douglas, 2000).

Both Kieffaber et al (2006) and Rentrop et al. (2010) utilized ex-Gussian modelling and found that their samples of participants with Sz had significantly higher tau parameters than the control group. Fassbender et al. (2014) estimated IIV by combining the variability of the normal component and the exponential component of the RT distribution found. They found that participants with Sz had increased IIV as well as a greater number of unusually long RTs relative to controls, which has been similarly found in previous studies (Rentrop et al., 2010; Kieffaber et al., 2006).

1.2.5. Motor slowing in Schizophrenia

So far the review has identified findings of slower, less accurate, and more variable responding in the Sz population. Alongside these deficits, individuals with Sz have also been documented to display much slower motor speeds compared with healthy populations which
creates a more complicated picture of decision making performance in Sz. Individuals with Sz have been described to have an overall reduction in motor activity, such as poverty of speech, decreased spontaneous movements, and a greater latency in movements (Liddle, 1987; Morrens et al., 2007). Fine motor impairments have also been described in Sz such as reduced baseline steadiness and excessive force used to produce responses (Vrtunski, Simpson, & Meltzer, 1989). Furthermore, relative to healthy controls, Sz participants are slower on finger lift RT (time to lift finger from resting button), traverse speed RT (time from lifting the finger to making the first key press), tapping speed, and manual dexterity (measuring on a peg-board test) (Rosofsky, Levin, & Holzman, 1982).

Although the literature review thus far has focused on CRT paradigms, some investigations into motor slowing utilizing more complex tasks such as line or figure copying, and symbol coding tasks (e.g., Morrens, Hulstijn, Van Hecke, Peuskens, & Sabbe, 2006; Morrens et al., 2008), will be briefly discussed. For instance, Jogems-Kosterman, Zitman, Van Hoof, and Hulstijn (2001) utilized a digitizing tablet and electronic pen to measure movement times during a copying task. Compared with controls, Sz participants required significantly longer initiation time (time before movement is started) and movement time (time needed to execute movements), but performed similarly in regards to movement velocity (actual writing time). The Sz participants wrote and drew larger in size than controls, which was suggested by Jogems-Kosterman et al. to be a compensation strategy for impaired motor control, which has been previously reported in Sz research (Gallucci, Phillips, Bradshaw, Vaddadi, & Pantelis, 1997; Vrtunski et al., 1989). However, it is important to acknowledge that copying and symbol coding tasks may involve numerous cognitive functions in the midst of the task, such as planning, inhibition, and attention, which may make it challenging to completely delineate motor time from cognitive processes.

In other studies utilizing less complex paradigms such as CRT and simple RT tasks, attempts have been made to separate motor or movement time from decision time. For
example, Fuller and Jananshahi (1999) defined movement time (MT) as the period of time between releasing a resting array and pressing the response button, and found that MT was significantly slower in the Sz group relative to controls. Krieger et al. (2001) measured MT in a similar manner but also investigated movement latency (ML), which was defined as the time between the occurrence of the stimuli and the finger leaving the resting array. The unmedicated participants with a 1st episode Sz had similar MT as controls, whereas the 1st episode Sz participants who had received 5-weeks of treatment with anti-psychotic medication, as well as the medicated Sz group with a chronic illness, had significantly slower MT. All groups performed as well as controls in terms of ML.

On the other hand, some contrasting findings have been reported in regards to motor slowing in Sz. Individuals with Sz have been described to have slower motor and cognitive processes, but that the speed of the latter is significantly more impaired (Nelson et al., 1990). Others have reported that individuals with Sz perform at a normal level on simple motor tests (Shakow, 1963) and no differences have been found between Sz and control groups on tasks such as finger tapping (Bervoets et al., 2014). Kim, Lee, Choi, and Goh (2009) investigated cognitive and motor performance on a CRT task with individuals with Sz. Cognitive or decision time was defined as the time between the presentation of the stimulus and the finger lifting from the resting button. Motor time was measured as described earlier. Kim et al., (2009) found that overall mean RT and decision times were significantly slower in the Sz group relative to controls, however motor time was not significantly different between groups.

These studies depict a mixed picture of results regarding motor speed in Sz and thus creates an unclear picture on the effect that motor slowing may be having on performance in CRT tasks that require speedy decision making for this population. Although a comprehensive discussion and review of motor slowing in Sz is outside of the scope of the present thesis, it is important to be mindful of the potential deficits that occur in this area for
individuals with Sz and how it may impact their decision making performance. Cognitive modelling approaches, which will be discussed in further detail in subsequent sections, attempt to estimate parameters such as non-decision time, which encompasses the time taken to encode a stimulus and produce a response. These modelling techniques may be able to provide further and insights into the various underlying factors in decision-making performance in Sz and the impact on any motor slowing that is occurring.

1.2.6 Summary

In conclusion, the research evidence reviewed above suggests that individuals with Sz tend to perform differently compared with control participants in tasks requiring speedy decision-making. Findings of slower RT in Sz has been linked to impairments in the decision and response selection aspects of information processing, and RT performance in Sz is particularly affected when task or response complexity is increased. Patterns in CRT performance across a variety of CRT paradigms suggest that Sz participants tend to be slower and less accurate than their healthy counterparts, however some mixed findings have been reported. Participants with Sz are also reported to have higher IIV compared with controls and this has been suggested to be due to the instability of information processing (Kaiser et al., 2008; Rentrop et al., 2010). The majority of the studies discussed used very simple CRT tasks that lead to high accuracy rates across groups, ranging between 90-95%. In other studies, accuracy is not reported or analysed further, which can preclude the investigation of potential speed-accuracy trade-offs occurring.

1.3 Stopping in Schizophrenia

1.3.1 Executive functioning

Executive functioning is not a unitary cognitive construct, but instead an umbrella terms that refers to a set of sub-components that together represent the executive system
(Miyake et al., 2000; Jurado & Rosselli, 2007). This system is responsible for regulating and monitoring behaviour and the ability to inhibit irrelevant or inappropriate responses is a key element of executive control (Logan & Cowan, 1984). A set of higher order skills are involved in executive functioning, such as inhibition, planning, working memory, direction of attention, and self-monitoring, all of which are aimed at regulating cognitive processes (Baddeley & Hitch, 1974; Delis, Kaplan, & Kramer, 2001; Lezak, Howieson, & Loring, 2004; Luria, 1966) have been found to be significantly impaired in Sz (e.g., Bryson, Whelahan, & Bell, 2001; Mahurin, Velligan, & Miller, 1998; Morice & Delahunty, 1996). Executive functioning deficits have been implicated as a major feature of Sz (Pantelis, Yucel, Wood, McGorry, & Velakoulis, 2003). Decline in executive functioning for individuals with Sz exceeds that of normal age-related changes of healthy individuals, as documented in cross-sectional data (Fucetola et al., 2000). More specifically, Sz has been associated with the impaired ability to inhibit planned responses that are no longer relevant across a variety of paradigms (Green, 1996; Fletcher, 2011). Response inhibition plays an important role in decision-making as it assists the individual to withhold a response that may be irrelevant or no longer required (Logan, 1985).

1.3.2 The stop-signal paradigm

The stop-signal paradigm is a widely used method of investigating response inhibition deficits in Sz (Verbruggen & Logan, 2008). In this paradigm, participants usually perform a CRT task (the “go” task), such as discriminating X’s from O’s by making a specific key press for each choice. On a small portion of the trials (e.g., 25%) a stop-signal, such as an auditory or visual stimulus, is presented to signal to the participant to withhold their primary response. The time between the presentation of the go-task stimulus and the stop-signal is called the stop-signal delay (SSD). Depending on the method employed, SSDs may be set at fixed
intervals or varied dynamically contingent upon the response of the participant (Logan, 1994).

Performance in the stop-signal paradigm is well explained by Logan and Cowan’s (1984) independent race model. According to this model, performance is the result of a race between two independent competing processes; the go-task process, which is triggered by the presentation of the go-task stimulus, and the stop process, which is triggered by the stop-signal. If the stop process finishes first, the response is withheld. If the go-task process finishes first a response is executed. The SSD will influence the finishing times of the stop process and as SSD is increased, the stop process starts later, effectively giving the go process a head start, making successful response inhibition less likely.

1.3.3 Measuring response inhibition in the stop-signal paradigm

The latency of the go task process is directly observable, and can be measured by RT on trials without a stop-signal. On the other hand, if the stop process wins the race, there is no observable response, so its latency cannot be measured directly, and so it must be estimated via a model (Logan, 1994). The latency of the stop process is called the stop-signal reaction time (SSRT). SSRT can be measured in a number of ways through SSDs that are either adjusted dynamically or set at a number of fixed values (see Logan, 1994, for further details). Specifically, SSRT refers to the time interval between the stop process starting (when it is triggered by the stop-signal) and the point at which the stop processes finishes. An individual’s SSRT can then be used to make inferences regarding the latency of their stopping process (Verbruggen & Logan, 2008).

It is also common practice for the probability of successful inhibition to be measured across a range of SSDs and the probability of successful inhibition plotted as a function of SSD (Logan, 1994). Inferences can be made regarding inhibitory performance by analysing the gradient of these inhibition functions and comparing them between groups (Logan, 1994).
A flatter inhibition function (i.e., change more slowly with SSD) indicates inhibitory deficits, which may be due to greater variability in the time taken to inhibit, and conversely, less variability results in steeper inhibition functions (Logan, 1994). If inhibition functions are different between groups this may suggest a difference in the variability of the stop process, variability in the go-task RT, or trigger failure (Logan, 1994).

Since inhibition functions are also influenced by variability in go-task RT, group differences in go RT variability can confound inferences about differences in inhibitory function based on slope differences (Verbruggen & Logan, 2009). One attempt at partialling out the variability of the go-task RT is the use of an alignment transformation called the Z relative finishing time (ZRFT), which involves plotting the inhibition functions in terms of a Z-score (Logan, 1994). If ZRFT transformation successfully aligns inhibition functions this indicates that the groups differed only in their go task variability (Logan & Cowan, 1984; Logan, 1994). On the other hand, if alignment does not occur, this can indicate group difference in stopping performance, either due to greater variability in the speed of the stop process or due to the stop process being triggered less often (Schachar & Logan, 1990; Logan, 1994; Tannock, Schachar, & Logan, 1995). Verbruggen and Logan (2009) note that tests for function alignment are usually done visually and quantitative methods for appraising alignment do not currently exist. Band, van der Molen, and Logan (2003) conducted Monte Carlo simulation in order to derive a series of guidelines regarding the best practice when using the stop-signal paradigm. They found that the ZRFT transformations do not reliably correct the influence of go-task variability on inhibition functions.

Trigger failure refers to the inhibitory process failing to start altogether, which may be due to the stop-signal not being detected or not being encoded properly (Band et al., 2003). Band et al (2003) suggested that even occasional trigger failures could significantly influence various measures of inhibition, including creating a considerable overestimation of SSRT. Despite its relevance to understanding inhibitory performance, trigger failure has not been
explored in detail in the literature and current methods interpreting ZRFT corrected inhibition functions have been found to be unreliable (Band et al., 2003). Logan (1994) suggested that a potential method of estimating trigger failure involves setting very short SSDs on some trials and investigating the probability of successful inhibition on these trials. Typically, if a stop-signal is presented very closely to the moment of the stimulus presentation, and the inhibition process is triggered, then response inhibition is highly likely (Verbruggen & Logan, 2009) and the probability of failing to inhibit at these SSDs can be representative of trigger failure.

1.3.4 Response inhibition deficits in Schizophrenia

Focusing specifically on studies utilizing the stop-signal paradigm, researchers have reported somewhat mixed results regarding the nature of response inhibition in Sz (Bellgrove et al., 2005). Badcock et al. (2002) produced one of the first studies that reported on stop-signal performance in Sz. They made comparisons between participants with Sz, those with non-schizophrenic psychosis and healthy controls and found that SSRT’s did not differ significantly between groups. However, they reported that the slope of the inhibition functions for both the Sz group and the psychosis comparison group was significantly flatter than the inhibition slope of the control group. Since these inhibition functions were not in alignment, a ZRFT transformation was applied in an attempt to partial out any variability in the go-task. The inhibition functions of the healthy control and the psychosis comparison group were aligned after this transformation with Badcock et al. (2002) suggesting that these two groups differed only in terms of variability of the go-task RT. Although, the participants with Sz and healthy controls still had significantly different inhibition functions, which Badcock et al (2002) explained was due to the Sz group having a deficiency in the stop process or that the stop process is triggered less often.

On the other hand, Enticott, Ogloff and Bradshaw (2008) found that participants with Sz had significantly increased SSRT than their healthy counterparts, suggesting this is due to
slower inhibitory processes. The authors found that the participants with Sz had a shallower inhibition function slope relative to controls and applying ZRFT transformation on the inhibition functions, they found no significant differences in the slopes between groups. Enticott et al. (2008) suggested that compared with controls, participants with Sz had significantly higher variability in responding to the go-task, however they had intact triggering of the inhibition process and same stop-process variability. However, as mentioned previously, the ZRFT transformation method has been found to be unreliable in correcting the influence of go-task variability on inhibition functions (Band et al., 2003) thus these results must be viewed with caution.

Bellgrove et al. (2005) found some differences between groups in regards to diagnosis type, reported that participants with the undifferentiated early-onset Sz diagnostic subtype displayed significantly longer SSRT’s compared with controls and participants with paranoid Sz, but this was only when responding with their left hand. No differences were reported between groups in regards to SSRT when responding with the right hand. Huddy et al. (2009) also studied a group of participants with Sz who were in the early course of their psychotic illness with a relatively larger sample of thirty-three Sz participants and healthy matched controls. In this study, participants with Sz had significantly slower SSRT’s compared with controls, and this result was significant even when differences in the go-task RT and IQ were taken into consideration. The presence of psychotic symptoms has been found to influence performance on the stop-signal task, with Yun et al. (2011) finding that those participants whose symptoms of Sz had remitted, performed similarly to the control group and their SSRT was not significantly different. Conversely, those participants whose symptoms were not remitted displayed significantly slower SSRT compared with healthy controls and the remitted participants.
As previously reported, saccadic RT has been found to be relatively unimpaired in Sz (Gale & Holzman, 2000; Iacono et al. 1981; Levin et al., 1981; Zahn et al., 1998) but in a study utilizing a saccadic countermanding task that required participants to inhibit planned visual saccades to stimuli following a stop-signal task, participants with Sz were found to have significantly longer SSRT’s compared with controls (Thakkar, Schall, Boucher, Logan, & Park, 2011).

Nolan, D’Angelo, and Hoptman (2011) investigated the connection between impulse control, self-reported aggression, and response inhibition. They found that participants with Sz scored higher on measures of impulsivity and aggression and exhibited a slower SSRT when compared with the control participants. Nolan et al. (2011) noted that a limitation of their study was that the tracking algorithm used to establish SSDs did not create uniform 50% stopping success and thus control participants inhibited more successfully than participants with SCZ. More recently, Hughes, Fulham, Johnston, and Michie (2012) investigated the neural basis for impaired inhibition in Sz by using fMRI and event-related potentials (ERPs). They also found that their sample of ten participants with Sz had significantly slower SSRTs compared with the healthy matched controls and also had reduced activation of the right inferior frontal gyrus (rIFG).

Although some mixed findings, there seems to be a consistent result that individuals with Sz are slower at inhibiting responses. One important consideration in this area of research is the possibility of trigger failure going undetected, and as previously suggested, even occasional trigger failures may lead to over-estimations of SSRT in the data (Band et al., 2003). It has been suggested that the failure to trigger the inhibition process could be due to not detecting or not decoding the signal properly (Band et al., 2003), and the likelihood of this occurring is worth investigating given the pronounced attention deficits that individuals with Sz have been reported to experience (e.g., Fioravanti, Carlone, Vitale, Cinti, & Clare, 2005; Schwartz, Tomlin, Evans, & Ross, 2001). Although some researchers have commented
on the triggering of the stop process in Sz by analysing inhibition functions (e.g. Badcock et al., 2002; Enticott et al., 2008), the ZRFT transformations that they have used have been brought into disrepute (Band et al., 2003). Therefore, it is important to investigate the occurrence of trigger failure further in future research.

1.3.5 Response inhibition and symptoms of Schizophrenia

In the aforementioned studies using the stop-signal paradigm, relationships between psychotic symptoms of Sz and SSRT were found. For instance, Thakkar et al. (2011) found a positive correlation between SSRT and negative symptoms of Sz, indicating that those with increased negative symptoms needed more time to inhibit visual saccades. Bellgrove et al. (2005) also found that the group of adolescent patients with early onset psychosis that had significantly longer SSRTs also had significantly higher negative symptoms. Individuals with Sz who were in the acute state of the illness exhibited significantly longer SSRT compared with participants whose Sz symptoms had remitted and healthy controls (Yun et al., 2011).

Aside from research utilizing the stop-signal paradigm, previous studies have used paradigms such as negative priming (Peters et al., 2000) and interference tasks (Brebion, Smith, Amado, Malaspina, & Gorman, 1998) to investigate associations between symptoms and inhibition deficits in Sz. Waters, Badcock, Maybery, and Michie (2003) proposed that positive symptoms such as auditory hallucinations represent failures in intentional inhibition rather than other forms of inhibition measured by priming or interference tasks, and that it is failure of the former type of inhibition that leads to the experience of unwanted and uncontrollable mental events. Waters et al. (2003) found that participants with Sz performed significantly worse than controls on measures of intentional inhibition of mental associations and irrelevant memories. They also found that auditory hallucination severity was linked to poorer intentional inhibition. Poor inhibitory control has also been linked to symptoms of Sz such as thought disorder (McCarley et al., 1999) and delusions (Peters et al., 2000). Frith
(1979) posited that symptoms such as auditory hallucinations could be linked to the inability to inhibit the output of preconscious processes and impairment in limiting the current contents of consciousness.

1.4 The present study

1.4.1 Scope of the experiment in the manuscript

The scope of the present experiment had originally aimed to investigate both the response slowing and inhibition displayed by individuals with Sz on a go-task and stop-signal task that spanned two testing sessions. A description of this original extended method (please see Appendix A) provides an outline of the experiment that was completed. However, due to the time constraints in the project, the research manuscript will only discuss the data obtained from the go-task of the experiment.

1.4.2 Meta-analysis

Schatz (1998) reviewed forty studies that employed a total of 196 CRT conditions and utilizing a regression-based approach, compared the relationship between the CRT performance of Sz and healthy control samples. The aim of this meta-analysis was to explore whether the RT slowing in Sz was due to a general slowing or perhaps more specific cognitive deficits. Schatz (1998) found that general slowing was a significant factor contributing to RT performance in Sz as it accounted for 87% of the variance. However, it seemed as though the extent of this slowing was also dependent on the particular type of information processing involved in the task. For instance, tasks requiring inhibition had the greatest slowing in RT for participants with Sz, followed by lexical tasks and the least impacted were non-lexical tasks.

The present study aims to update Schatz’s (1998) meta-analysis by including more recently published studies, but to also extend it by collecting accuracy and standard deviation
data in addition to RT data, which was not done by Schatz. Although it has been noted in individual studies that choice accuracy is generally reduced in Sz, we are not aware of any systematic and wide-ranging study of this issue. By investigating accuracy rates as well as RT, this may provide further insights into the possibility of speed-accuracy trade-offs occurring. For instance, if slowing in Sz is due to a speed-accuracy trade-off then patterns of higher accuracy in these samples may be observed. Similarly, a systematic review of standard deviation data across CRT tasks in Sz has not been previously conducted or included in Schatz’s (1998) work and will be another focus of the present study to further extend on findings of IIV differences in Sz relative to controls. The meta-analysis will include the articles reviewed by Schatz and augment this sample by selecting articles published in the period of 1996 – 2014. The search will be done using the same criteria as Schatz’s, by searching the key work “schizophrenia” combined separately with the key words “reaction time”, “lexical”, “semantic”, and “inhibition” in the PsychInfo and Medline databases.

### 1.4.3 Modelling approaches

In addition to completing traditional analyses of performance on the CRT task in the present experiment, such as comparing meant RTs and accuracy rates across groups, modelling analyses will also be computed, by fitting the data to the Drift-Diffusion Model (DDM; Ratcliff & McKoon, 2008) and the Linear Ballistic Accumulator (LBA; Brown & Heathcote, 2008) model, and making relevant comparisons. The specific method, analyses and parameters derived via these modelling procedures are explained further in the research manuscript, and a brief review of relevant parameters will be provided here. These types of modelling approaches have not been previously utilized to investigate CRT performance in Sz populations and have the potential to uncover further underlying variables in speeded decision-making.
The DDM and LBA models share a simple common idea that participants accumulate information (evidence) about the choice over time, and response selection occurs once the threshold amount of evidence has been accrued. The speed of evidence accumulation is referred to as the drift rate. A core concept for these models is that choice involves a speed-accuracy trade-off; as the threshold is increased choices become more accurate because they are based on more evidence, but they are also slower because it takes longer to collect this evidence. These models predict RT as the sum of decision time – the time from when evidence starts accumulating until that evidence first crosses a threshold – and non-decision time. Non-decision time is the sum of the time to encode the stimulus and the time to produce the response corresponding to the decision.

In the DDM model (Figure 1), a single unit accumulates the difference in evidence favouring a left response minus evidence favouring a right response (i.e., positive evidence favours left and negative right). If the evidence total reaches the upper threshold a left decision is made and if it reaches the lower threshold a right decision is made. One of the ways in which the LBA model (Figure 2) differs from the DDM is that a separate accumulator represents each choice option. Rapid choices are modelled as a race between the two accumulations, which continues until one of the accumulators reaches the threshold and a response is elicited. Both models capture response bias via the start point parameter, which refers to the starting amount of evidence for a particular decision at the start of each trial. For instance, this may be influenced by expectations about what the stimulus will be before seeing it or perhaps what the response was on the previous trial. A more comprehensive review of the assumptions and differences in the DDM and LBA models are discussed in the research manuscript.
Figure 1. The Drift-Diffusion Model (DDM) for a left vs. right decision. U() indicates a uniform distribution and N() a normal distribution.
One advantage to evidence-accumulation models is that they provide a complete characterization of choice behaviour, accounting not only for mean RT but also for accuracy and the full distribution of RT (i.e., its level of variability and the typically positively skewed shape) for each choice. Another advantage is that differential effects on model parameters can identify the underlying causes of deficits. For example, slowing may be due to lower quality
evidence, so that it accumulates at a slower rate, or it may be due to participants requiring more evidence (i.e., a higher threshold), or it could be due to slowing in processes in non-decision process, such as the time to encode the stimulus or produce a response. These advantages have lead to the increasing use of these models to understand the causes of cognitive impairments resulting from factors that range from sleep deprivation and alcohol (Ratcliff & Van Dongen, 2011; van Ravenzwaaij, Dutilh, & Wagenmakers, 2012) to depression and anxiety (Ho et al., 2014; White, Ratcliff, Vasey & McKoon, 2010a, 2010b).

For instance in aging literature, it had been widely assumed that age-related slowing had a single cause, a general reduction in the rate of information processing, however applications of the LBA revealed that slowing in older populations was not actually due to slower evidence accumulation as previously hypothesized, but in fact due to a higher threshold setting (e.g., Forstmann et al., 2011). Slowing was occurring due to older participants trading speed for accuracy by employing a higher degree of caution in their responding. Other studies have consistently shown similar results using modelling approaches in that- apart from a few cases where aging caused sensory degradation in a perceptual choice task – age does not affect the rate of evidence accumulation (e.g. Ratcliff, Love & Opfer, 2011; Ratcliff, Thapar & McKoon, 2001; Thapar, Ratcliff & McKoon, 2003).

These studies highlight the advantage that modelling techniques present in regards to investigating the underlying cognitive processes in decision making that may not have been revealed with traditional analyses such as comparing mean RT and accuracy rates between groups. To our knowledge, these modelling approaches have not been previously applied to deficits in CRT in Sz. For instance, these applications may help to uncover whether slowing in Sz is due to non-decision processes, such as slowing in the encoding of the stimulus or motor slowing in the production of the response for individuals with Sz. Or perhaps slowing may be attributed to lower quality evidence accumulation so that evidence accumulates at a slower rate. It would also be interesting to investigate whether individuals with Sz set
different threshold parameters to healthy controls groups and whether the amount of evidence required for them to reach a decision significantly influences their CRT performance. Thus, it is of value to carry out modelling investigations on the CRT performance of individuals with Sz with the hope of uncovering further insights into the nature of their deficits and underlying factors.

1.4.4 Nature of the task used

As discussed previously, majority of the studies using CRT paradigms often involve tasks that require attending to relatively straight-forward stimuli (e.g. discriminating between “X’s” and “O’s) and thus tend to result in highly accurate performance across groups that is often near ceiling levels. The stimuli for the present study comprises of a random dot kinematogram (RDK) stimulus, which consists of a number of randomly moving dots, with a proportion of these dots moving coherently either to the top left or top right. This type of stimulus was chosen in order to investigate performance on a task that is relatively difficult and is aimed at producing more errors. The potential for accuracy floor or ceiling effects to occur will be addressed by having three levels of difficulty determined by the level of coherence in the RDK (i.e., percentage of dots traveling in the same direction).

1.4.5 Hypotheses

Following on from the literature review and the aims of the present study discussed above, a number of hypotheses are presented below that will be investigated further in the research manuscript in the next chapter.

Meta-analysis

1. It is hypothesized that the meta-analysis will reveal a systematic pattern of slower mean RT across the Sz samples relative to the control samples.
2. It is hypothesized that accuracy will also be systematically slower across Sz samples relative to control samples.

3. It is hypothesized that a pattern of increased RT standard deviation will be observed for the Sz samples relative to control samples.

Experiment
1. Traditional analyses:
   a. It is hypothesized that in the comparisons of mean RT, the group comprising of participants with Sz will be found to be significantly slower relative to the control group.
   b. It is hypothesized that participants with Sz will also show significantly less accurate performance compared with the control group.
   c. It is hypothesized that significantly increased RT standard deviation for the Sz sample will be observed relative to the control group.

2. Modelling analyses:
   a. It is hypothesized that the participants with Sz will exhibit lower quality evidence accumulation represented by lower drift parameter estimates relative to the control group.
   b. It is hypothesized that non-decision time will also be slower in the Sz relative to the control group, given the previous findings of motor slowing in Sz.
   c. Since modelling approaches have not been conducted on CRT performance in Sz previously, it is difficult to produce a hypothesis in relation to the threshold parameter that is guided by previous findings. This will be an exploratory research question to investigate whether
individuals with Sz adjust their evidence accumulation thresholds differently to their healthy counter-parts.
2. RESEARCH MANUSCRIPT

Decision processes and the slowing of simple choices in Schizophrenia

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2.1 Abstract

Individuals with Schizophrenia have been described to experience a number of cognitive deficits that span across several domains and have been found to be strong predictors of functional outcomes. Significantly slower performance on a variety of reaction time paradigms has been documented consistently in Schizophrenia research. Reaction choice paradigms that require rapid choices between two or more options were the focus of the present paper and were reviewed in a meta-analysis. An experiment was also carried out comparing the performance of participants with Schizophrenia and healthy controls on a choice reaction time task and the data were fit by two cognitive models of choice processing: the Drift-Diffusion Model (DDM, Ratcliff & McKoon, 2008) and the Linear Ballistic Accumulator (LBA, Brown & Heathcote, 2008) model. The meta-analysis revealed a consistent pattern of slower and more error-prone responding in Schizophrenia samples relative to controls. Overall, the LBA model fit was better and produced more significant results compared with the DDM model. Sequential effects were found, as participants with Schizophrenia were more likely to repeat their last response. The Schizophrenia group had higher threshold parameters than controls indicating that they required more evidence to make a choice, and had reduced evidence quality leading to slower and less accurate responding. These results are discussed in light of relevant literature.

Keywords: schizophrenia, choice reaction time, modelling, cognitive deficits
2.2 Introduction

Schizophrenia is characterized by a broad range of disturbances in cognition, behaviour, emotion, and perception (Frangou & Kington, 2004). Clinical manifestations, including positive (e.g., hallucinations, delusions, disorganised speech and behaviour) and negative (e.g., poverty of thought and speech, social withdrawal, blunted and flat effect, and a loss of motivation and experience of pleasure) symptoms are accompanied by cognitive impairments that occur across several domains in almost all cases (Keefe & Harvey, 2012). Cognitive impairment is a stronger predictor of functional outcomes and quality of life over and above clinical symptoms (Nuechterlein et al., 2011) and is not simply as a result of clinical symptoms or medication effects (Green, Kern, Braff, & Mintz, 2000). The MATRICS project (Green et al., 2004) identified the most significant cognitive-deficit domains as social cognition, working memory, attention/vigilance, verbal learning and memory, visual learning and memory, reasoning and problem solving, and speed of processing. Our focus in this paper is on the latter domain, and in particular, response time (RT) in tasks requiring a rapid choice between two or more alterative responses.

Wells and Kelley (1922) summarized early research showing markedly slower simple RT (i.e., responding to a target stimulus without making a choice) in patients with psychosis compared with healthy participants. Much early work focused on simple RT and the way in which it is affected by preceding events, particularly a shift in target’s sensory modality relative to the last trial (e.g., Mowrer, 1941; Sutton, Hakarem, Zubin, & Portnoy, 1961) and the effect of time between a signal to prepare to respond and the occurrence of the target stimulus (e.g., Huston, Shakow & Riggs, 1937; Rodnick & Shakow, 1940). The latter preparation-interval effect has been suggested as a disease marker for individuals at risk of developing Schizophrenia (Maier et al., 1994). Zubin (1975) proposed that these effects occur because prior events leave behind facilitatory or inhibitory neuronal traces that tend to last longer in Schizophrenia than in healthy groups. Subsequent research has shown slowing for
Schizophrenia relative to control groups across an extensive variety of simple RT tasks and paradigms requiring manual responses, and this slowing has been associated with poorer prognosis and poorer outcomes (Nuechterlein, 1977).

Our focus here is on choice RT paradigms, where participants are required to make a quick choice among two or more options. This kind of paradigm, where RT is typically less than two to three seconds, has been widely used to study impairment in a range of perceptual and cognitive processes in Schizophrenia because it is relatively free from strategies and multiple-stage higher-order judgements required in more complex decision-making tasks. Schatz (1998) provided a meta-analysis of mean RT in mainly choice tasks with results from 196 conditions drawn from 40 papers. He classified tasks into inhibition, lexical and non-lexical types and found slowing for Schizophrenia relative to control groups was pervasive. Although there are some exceptions, slowing is generally found to be disproportionately greater in choice than simple RT (Benton, Jentsch, & Wahler, 1959; Hintze, Bebenek, Kuhn-Dymecka, Wronska & Wciorka, 2006; Krieger et al., 2001, 2005; Karras, 1967; Zahn et al., 1998). Evidence from neuroscience has supported deficits specific to choice processing. Using evoked potentials, Luck et al. (2009) found a normal P3 component but a smaller and later LRP (lateralized readiness potential) in Schizophrenia, and concluded that slowing in choice RT was due to an impairment in the response selection stage after perceptual and categorization processes. In a follow-up study Kappenman et al. (2012) found a deficit in activating the correct response rather than increased activation of the incorrect response. Using fMRI, Woodward et al. (2009) found marked reductions in functional connectivity between multiple brain regions and dorsolateral prefrontal cortex in a choice RT task.

We studied choice RT processes in Schizophrenia using cognitive models of choice processing. Although a number of variants of these models have been proposed, such as the Drift-Diffusion model (DDM, Ratcliff & McKoon, 2008) and the Linear Ballistic Accumulator (LBA, Brown & Heathcote, 2008), they share a simple common idea that
participants accumulate information about the choice (evidence) over time, with response selection occurring when a threshold amount of evidence has accrued. A core concept for these models is that choice involves a speed-accuracy trade-off; as the threshold is increased choices become more accurate because they are based on more evidence, but they also slow because it takes longer to collect the evidence. Model parameters accounting for speed-accuracy trade-offs have been directly linked to underlying neural structures (Forstmann et al., 2008, 2010; Mansfield et al., 2010).

One advantage of evidence-accumulation models is that they provide a complete characterization of choice behaviour, accounting not only for mean RT but also for accuracy and the full distribution of RT (i.e., its level of variability and the typically positively skewed shape) for each choice. Another advantage is that differential effects on model parameters can identify the underlying causes of deficits. For example, slowing may be due to lower quality evidence, so that it accumulates at a slower rate, or it may be due to participants requiring more evidence (i.e., a higher threshold), or it could be due to slowing in processes in non-decision process, such as the time to encode the stimulus or produce a response. These advantages have lead to the increasing use of these models to understand the causes of cognitive impairments resulting from factors that range from sleep deprivation and alcohol (Ratcliff & Van Dongen, 2011; van Ravenzwaaij, Dutilh, & Wagenmakers, 2012) to depression and anxiety (Ho et al., 2014; White, Ratcliff, Vasey & McKoon, 2010a, 2010b). However, they have not, to our knowledge, been previously applied to deficits in choice RT in Schizophrenia.

In the first part of this paper we report the results of a meta-analysis that updates the work of Schatz (1998) and extends it from mean RT to accuracy. Although it has been noted in individual studies that choice accuracy is generally reduced in Schizophrenia, we are not aware of any systematic and wide-ranging study of this issue. If slowing in Schizophrenia is due to reduced quality of evidence, we would expect accuracy to also be systematically
lower. If it is due to a speed-accuracy trade-off, then accuracy should be increased. If both factors are in play to varying degrees across different tasks and conditions a mixed pattern may emerge.

Although the results of the meta-analysis on accuracy and mean RT will be useful to provide a general context for understanding choice RT in Schizophrenia they are not complete, because they do not take account of effects on the distribution of RT, and they cannot be definitive on the issue of speed-accuracy trade-off, because other factors may be affecting slowing, such as non-decision time. In second part of the paper we report the results of fitting both the DDM and LBA models to data from a new experiment. Patients with Schizophrenia and control participants decided the direction of motion in random-dot kinematogram (RDK) stimuli – clouds of mostly randomly moving dots with a proportion that move coherently either left or right. Manipulation of the proportion of coherently moving dots allowed us to calibrate the displays to avoid floor and ceiling effects in accuracy, which facilitates better estimation of model parameters. Tailoring difficulty to participant’s abilities also encouraged engagement among patients, which along with the use of a simple task aimed to address confounding by motivational factors (Joyce & Huddy, 2004).

2.3 Meta-analysis of Choice RT Studies

Schatz (1998) adopted Cerella’s (1995) Brinley plot (Brinley, 1965; Salthouse & Somberg, 1982) methodology, where results from two groups are plotted against each other. Cerella inferred general slowing due to aging from a strong linear relationship ($r^2 = .89$) with a slope of 1.35 in plots of young against old RT. Schatz reported similar findings with control RT explaining 87% of the variance in the Schizophrenia group’s RT. He divided tasks into lexical, non-lexical and inhibitory types and reported slopes of 1.75, 1.39 and 2.3 respectively, but noted the effect size for these differences was small.
Since Schatz’s (1998) work it has been shown that a regression slope greater than one in a Brinley plot does not indicate anything about general slowing, but rather it indicates a difference in the standard deviation of the groups RT distributions (Ratcliff, Spieler & McKoon, 2000). Ratcliff et al. showed that a regression analysis of Brinley plots is relatively uninformative (see also Cerella, 1994), with a slope greater than one having multiple potential causes. For example, it is consistent with a DDM model with a higher response threshold or a lower evidence accumulation rate for old than young participants. Ratcliff et al. recommend a DDM analysis be used instead of Brinley plots because it provides a qualitatively deeper understanding of the cognitive mechanism that mediate aging effects. Subsequently, Ratcliff and colleagues have followed up on this recommendation in an impressive and wide-ranging series of studies (Ratcliff, Love & Opfer, 2011; Ratcliff, Thapar & McKoon, 2001, 2003, 2004, 2006a, 2006b, 2007, 2010, 2011; Ratcliff, Thapar, Gómez & McKoon, 2004; Thapar, Ratcliff & McKoon, 2003). These studies have consistently shown that – apart from a few cases where aging caused sensory degradation in a perceptual choice task – age does not affect the rate of evidence accumulation. Rather, slowing occurs because older participants set a higher response threshold (i.e., they trade speed for accuracy), and to a lesser degree due to a slowing in non-decision time by between 0.05s to 0.1s. Previously, it had been widely assumed that age-related slowing had a single cause, a general reduction in the rate of information processing.

Although we agree with Ratcliff et al.’s (2000) conclusions about the potential utility of DDM analysis and the shortcomings of regression analyses of Brinley plots, Schatz’s (1998) meta-analysis remains highly informative in the way it systematically demonstrates the pervasive nature of slowing in Schizophrenia across a broad range of tasks. A Brinley plot is also useful for slowing results, with slowing being indicated by points falling above the main diagonal, as show in Figure 3. Starting from the list provided by Schatz we added more recent articles by searching for the key word "schizophrenia" combined separately with the
key words "reaction time", "lexical", "semantic", and "inhibition" in the PsychInfo and Medline databases, selecting articles published in the period 1996 - 2014. Together both sources yielded 83 papers that reported on 317 conditions and gave numerical results for one or more of average correct RT (i.e., the mean or median RT for correct responses) and accuracy for both Schizophrenia and control groups. We were also interested in confirming the difference in RT standard deviations implied by the slopes greater than one reported by Schatz, so where available we also recorded the mean of individual participant’s correct RT standard deviation (or both a coefficient of variation and mean from which it could be calculated).

Figure 3. Average RT for correct responses and percentage of correct responses for choice RT tasks. The dotted diagonal line indicates equality between the two groups. Tasks were classified as inhibition, lexical or non-lexical. Results for the present experiment are for the 10% coherence condition. In order to improve the resolution of other results the RT panel excludes Schneider’s (2011) inhibition-task data, where SZ=6.1s and Control=4.5s.

The variety of tasks in our set of papers was very similar to that in Schatz’s (1998) sample, except that simple RT tasks (i.e., tasks which did not require a choice among different response options) were excluded as our focus is on choice RT. As in Schatz tasks were classified on the basis of whether the choice was from an inhibition task (e.g., Stroop: 180 conditions) a lexical task (i.e., decisions about words, 67 conditions) or a non-lexical task.

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(i.e., perceptual decisions, 70 conditions). Overall, mean RT results were reported for 314 conditions (179 inhibition, 67 lexical and 68 non-lexical), accuracy results were reported for 189 conditions (118 inhibition, 35 lexical and 36 non-lexical), and standard deviations were reported for 9 conditions (5 inhibition, 2 lexical and 3 non-lexical).

Given the small number of observations available, we did not break the standard deviations down by task type. Despite the small sample size the average standard deviation for the Schizophrenia group (0.140s) was significantly greater than the control group average (0.099s), \( t(8) = 12, p < .001 \), by a factor very similar to that indicated by the slope in Schatz’s analysis. Looking at the 7 cases that had both statistics, the difference in group means and standard deviations was almost exactly equal (.042 vs. .041s) and proportionally the standard deviation difference was larger (1.44 vs. 1.09).

The left panel of Figure 3 shows that slowing is a highly consistent result, with only 6/314 cases (1.9%) below the main diagonal (i.e., the dotted line indicating equal results for the two groups). Overall, the control groups (0.67s) were significantly faster than the Schizophrenia groups (0.91s), \( t(313) = 17.5, p < .001 \), and this was true separately for the inhibition (0.6s vs. 0.79s), \( t(178) = 14.1, p < .001 \), lexical (0.7s vs. 0.92s), \( t(66) = 8.9, p < .001 \), and non-lexical (0.83s vs. 0.123s), \( t(67) = 9.5, p < .001 \), task groups. There was one large outlying inhibition-task result (Schneider, 2011), this had little effect on the group difference, lexical (0.58s vs. 0.76s), \( t(66) = 16.5, p < .001 \).

The right panel of Figure 3 shows that accuracy was close to ceiling in most cases; on average over groups 72% of conditions had accuracy greater than 95% and 87% of conditions with average accuracy greater than 90%. In general accuracy was less for the Schizophrenia than control groups (i.e., point below the main diagonal), although this effect was not as consistent as for slowing, with 32/189 cases (17%) above the main diagonal. These cases against the general trend did not appear to be due to ceiling effects as they were more
prevalent in lower accuracy conditions (19% and 24% for conditions with less than or equal to 95% and 90% average accuracy respectively).

Overall, the control groups (96.6%) were significantly more accurate than the Schizophrenia groups (94.2%), \( t(188) = 7.7, p < .001 \), and again this was true separately for the inhibition (96.4% vs. 94.4%), \( t(117) = 6.2, p < .001 \), lexical (96.6% vs. 93.7%), \( t(34) = 4.3, p < .001 \), and non-lexical (97.2% vs. 94.2%), \( t(35) = 3, p = .005 \), task groups. Similar results were obtained when conditions near ceiling were removed (average accuracy greater than 95%), both overall (91.3% vs. 86%), \( t(52) = 6, p < .001 \), and for the inhibition (90.8% vs. 87.6%), \( t(32) = 3.2, p = .003 \), lexical (92.1% vs. 84.3%), \( t(9) = 7.2, p < .001 \), and non-lexical (92% vs. 92.6%), \( t(9) = 33.6, p = .006 \), task groups.

The findings reported so far are consistent with slowing being mediated by lower drift rate for the participants with Schizophrenia, as this would cause both slower, more variable, and more error prone responding. As a further check we examined the correlation of the Schizophrenia minus control group average RT differences with the corresponding accuracy differences. If the differences were mediated by drift rate then a negative correlation would be expected. There were a good number of cases, 188, where the required results were available and the resulting correlation was negative, but it was small, \( r = -0.09 \), and non-significant, \( t(186) = 1.3, p = .2 \). The weak correlation was not due to the large number of conditions near ceiling, as when cases with greater than 95% average accuracy were removed the correlation weakened, \( r = -0.06, t(51) = 0.46, p = 0.65 \).

These results indicate that there might be another factor, such as a threshold difference, that also mediates the group differences. Although it is unlikely that a threshold difference alone could be an explanation (e.g., if the Schizophrenia group was slower because they had a higher threshold they should also be more accurate) it could combine with a drift rate difference to explain the pattern of results. For example, the participants with Schizophrenia might attempt to compensate for the lower accuracy caused by a lower drift.
rate by raising their threshold. If they did not do so sufficiently to fully compensate they could still be less accurate, but have an even bigger disadvantage in speed, and the correlation between speed and accuracy differences would be reduced or even absent. However, these possibilities must remain speculations with respect to the studies that contributed to the meta-analysis as we have reached the limits of the available data. The experiment we performed enabled us to overcome these limitations.

2.4 Experiment

Participants were tested either with a harder pair of motion-coherence levels, 5% and 10%, or an easier pair, 10% and 20%. The 10% coherence trials common to all participants were used to test performance under physically identical conditions. Several blocks of trials at the start of the experiment were used to select the pair that best avoided floor and ceiling effects (i.e., less able participants were allocated the easy pair and more able participants the harder pair). In particular, we wished to avoid the near ceiling performance in accuracy observed in the results from many previous studies displayed in Figure 3. Figure 3 shows, for the 10% coherence condition, that our calibration procedure successfully achieves this aim.

The difficulty manipulation instantiated by the difference between pair members – with the higher-coherence level constituting the easy condition and lower-coherence level the hard condition – was included to validate the models. Previous research has found that coherence selectively influences parameters related to the rate of evidence accumulation (e.g., Forstmann et al., 2008). Hence, a valid model should be able to provide a good fit to the data when only rate parameters are allowed to vary as a function of difficulty.

When we initially fit the LBA model we noticed much larger estimates of a parameter measuring random biases in the evidence accumulation processes caused by a difference in the starting level of evidence for each choice present before the stimulus is presented. In an earlier application of a pre-cursor to the LBA (Brown & Heathcote, 2005) in a model of the
absolute-identification task (Brown, Marley, Donkin & Heathcote, 2008) these random biases were in part explained by a carry-over effect from the last trial. This prompted us to test our data for such sequential effects by examining the autocorrelations between choices (i.e., the degree to which the choice made on one trial predicts the choice made on the next trial) and to explicitly allow for them in our modelling, as we now report.

2.5 Method

2.5.1 Participants

Informed consent was obtained from all participants prior to the commencement of the study. Participants were excluded if they had a history of neurological trauma, a diagnosis of intellectual disability, or current drug or alcohol dependence. A total of twenty-six participants with Schizophrenia or Schizoaffective disorder who were recruited from a clozapine clinic held at the Newcastle Community Mental Health Service. They were paid $55 for their participation, which included an extra session completing a stop-signal task that is not reported here. The treating clinician or case manager confirmed the participant’s diagnosis, their ability to provide informed consent, and whether the study would be suitable for them.

Seven participants were excluded from further analyses, six with Schizophrenia and one with a Schizoaffective disorder. One was excluded because they declined to complete the clinical interview and six due to chance accuracy in the choice task. Table 1 provides a summary of the remaining participants’ demographics and medication taken at the time of testing. One participant reported undergoing a series of maintenance electroconvulsive therapy treatments in the six months prior to participating in the research study. On average the excluded participants were slightly older (44.6 years) and had more negative symptoms (12.5) but had similar positive symptoms (2.8), disorganization (2.3), LNS (7.7), WTAR (94) and education (2.6) to those included.
Healthy controls were excluded from participating if they met any of the exclusion criteria for the Schizophrenia group or if they had a diagnosis of a mental illness. Nineteen control participants were recruited and matched with the clinical participants by age and gender. Participants were recruited from the University of Newcastle (n = 4) from a student pool register and were awarded course credit for their participation. Other healthy controls were recruited from the Hunter Medical Research Institute volunteer register (n = 6) and from the local community (n= 9), and received reimbursement of $40 to cover the costs associated with participation.

Table 1. Participant characteristics.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Schizophrenia (n = 19)</th>
<th>Controls (n = 19)</th>
<th>Parametric test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>t values</td>
</tr>
<tr>
<td>Age (years)</td>
<td>37.6 (6.5)</td>
<td>38.8 (9.0)</td>
<td>0.5</td>
</tr>
<tr>
<td>Education*</td>
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<td>5 (0.8)</td>
<td>6.1</td>
</tr>
<tr>
<td>WTAR scaled score</td>
<td>94 (15.4)</td>
<td>109.4 (24.7)</td>
<td>2.3</td>
</tr>
<tr>
<td>LNS scaled score</td>
<td>8.1 (2.5)</td>
<td>11.5 (3.7)</td>
<td>3.4</td>
</tr>
<tr>
<td>SAPS</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>SANS</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Disorganization symptoms</td>
<td>2.4 (2.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>16 (84.2)</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>3 (15.8)</td>
<td>3 (15.8)</td>
<td></td>
</tr>
<tr>
<td>Diagnosis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schizophrenia</td>
<td>17 (89.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schizoaffective disorder</td>
<td>2 (10.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medication type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clozapine</td>
<td>18 (94.7)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other atypical antipsychotics</td>
<td>10 (52.6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical antipsychotics</td>
<td>1 (5.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antidepressants</td>
<td>7 (36.8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lithium carbonate</td>
<td>1 (5.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anticonvulsants</td>
<td>3 (15.8)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.5.2 Experimental Apparatus and Stimuli

The RDK stimuli were presented on a personal computer in a quiet room. This RDK consisted of 40 dots within an invisible circular border area 50mm in diameter. The dots moved randomly, being redrawn at the rate of 30 frames per second, except for a proportion of dots that moved coherently 45 degrees either to the top left or top right direction. The proportion of dots moving coherently in one direction determined the difficulty of the trial, so that the higher the coherence, the easier it was to determine the direction of the dots. Participants were instructed to judge the direction of the movement of the dots by pressing the “Z” key with their left hand for left movement or the “/” with their right hand for right movement.

A fixation point of 250ms preceded each presentation of the RDK stimulus. Initially, the inter-stimulus interval for each trial was fixed at 2s, however preliminary data analysis revealed that some participants’ RT distributions were truncated at the 2s mark. As a result, the length of stimulus presentation was extended to a fixed length of 3s. The inter-stimulus interval was 0.5s in duration.

The experimental task comprised 9 blocks with 49 trials in each block, with the first block being a practice block intended to allow participants to familiarise themselves with the task. In the practice block, the coherence of dots started at 65%, and decreased gradually (e.g., 65%, 54%, 48%, and so on) until it reached 20%. The second and third blocks contained three difficult levels, 5%, 10%, and 20% coherence and the average accuracy was determined for the easier pair (10% and 20%) and the harder pair (5% and 10%). Whichever coherence pair had an average accuracy closer to 75% was used as the difficulty level for the remaining blocks. Between each block, participants were encouraged to take a rest for as long

* Education codes: 0 = below Year 10, 1 = Year 10/4th form (school certificate/equivalent), 2 = Year 11/5th form (leaving certificate/equivalent), 3 = Year 12/6th form (HSC/equivalent), 4 = Technical College or TAFE College, 5 = Graduate (Bachelor degree), 6 = Post-graduate (Masters degree/PhD).
as they required and continue onto the next block by pressing the space bar. The task took approximately 20 minutes to complete.

Participants were encouraged to perform quickly but also to try to be accurate in their responding. For correct responses, participants were provided with feedback on their reaction time in milliseconds in order to increase motivation and reinforce rapid responding. Incorrect choices were followed by “incorrect” displayed on the screen and “too slow” if participants failed to respond within 3s.

2.5.3 Psychometric Measures

Participants completed the Letter-Number Sequence (LNS), which is a subtest of the Wechsler Adult Intelligence Scale, third edition (WAIS-III; Wechsler, 1997) as a measure of working memory. In this test, the participants were orally presented with a series of letters and numbers in a mixed-up order, and were required to repeat them by arranging the numbers in chronological order, followed by the letters in alphabetical order. All participants also completed The Wechsler Test of Adult Reading (WTAR) (The Psychological Corporation, 2001) which assesses premorbid functioning in adults. In this task, participants were presented with a word card and were required to pronounce 50 irregularly spelled words.

Patients were administered The Scale for the Assessment of Positive and Negative Symptoms (SAPS/SANS) (Andreasen, 1983; 1984), which took approximately 45 minutes to 1 hour to administer, depending on the extent of the symptoms. The SAPS/SANS has been found to have good inter-rater reliability, modest internal consistency and strong construct validity (Peralta & Cuesta, 1994). In line with the principal components analysis of the SAPS/SANS by Andreasen, Arndt, Alliger, Miller and Flaum (1995), positive symptoms (SAPS score) consisted of the combined global scores for hallucinations and delusions, disorganization symptoms comprised of global scores for bizarre behaviour and positive formal thought disorder, and negative symptoms (SANS score) combines the global scores
for affective flattening, alogia, avolition-aphathy, and anhedonia-asociality. Scores on the attention subscale of the SAPS/SANS were omitted, as it is not considered to be a core component of negative symptomology (Blanchard & Cohen, 2006).

2.5.4 Procedure

The complete experiment took place over two separate sessions, typically a week apart and at a minimum 24 hours apart. On average, the time between the first and second session was 8.8 days (SD = 3.1) for the Schizophrenia group, and 9.4 days (SD = 6.5) for the control group. In the first session, participants completed a demographic questionnaire, the choice task, the LNS, and the WTAR. In the second session, all participants completed the stop-task (which is not reported here) and participants with Schizophrenia also completed the clinical interview.

2.6 Results

We performed an analysis of accuracy and RT for correct responses using ANOVAs with factors for 1) current stimulus (left vs. right motion), 2) last response (left vs. right), 3) difficulty (higher vs. lower coherence), and 4) group (patients vs. controls). We report all effects significant at the 0.05 level.

Mean correct RT was significantly slower for the lower coherence stimuli (1.1s) than the higher coherence stimuli (0.93s), $F(1,36) = 68, p < .001$. The same was true for median RT (0.99s vs. 0.86s), $F(1,36) = 50, p < .001$. The correct RT standard deviation was also greater for lower (0.38s) than higher (3.8s) coherence stimuli, $F(1,36) = 76, p < .001$, and this effect interacted with group, $F(1,36) = 9.5, p = .003$, due to a larger effect in the control group. Accuracy was less for low (84%) than high (71%) coherence stimuli, $F(1,36) = 71, p < .001$, less for left (75%) than right (80%) stimuli, $F(1,36) = 4.9, p = .03$, and less for the Schizophrenia (72%) than control (82%) group, $F(1,36) = 10, p = .003$. 
The tests just described involving the group factor are confounded by our difficulty-calibration procedure, which assigned higher-coherence (10% and 20%) – and hence easier – pairs more often in the Schizophrenia (16/19) than control (11/19) group. Hence, we repeated the tests with only data from the 10% coherence condition common to all participants.

Mean RT for correct responses was slower in the Schizophrenia (1s) than control (0.93s) group, but the difference was not significant, F<1. The same was true for the median (0.93s vs. 0.85s), F(1,36) = 1.2, p = .27. The RT standard deviation for correct responses was greater in the Schizophrenia (0.36s) than control (0.32s) group, but the difference was not significant, F(1,36) = 1, p = .32. Finally, accuracy was less in the Schizophrenia (83%) than control (78%) group, but again the difference was not significant, F(1,36) = 1.8, p = .18.

Finally, we examined the probability of making a left vs. right response to check for response bias. Overall, there was a small but highly significant bias to right responses, p(left) = .47, t(37) = 3.7, p < .001. An ANOVA did not find any significant main effects of group or last response. The same was true for data from only the 10% coherence conditions.

2.6.1 Sequential Effects

To test for sequential effects we fit an autoregressive model of order one to each participant’s binary response choices (i.e., left or right) for each of the 6 experimental blocks of trials. This yielded estimates of the proportion of variance in the current response choice explained by the previous response choice (i.e., lag-one squared correlation estimates). In an ANOVA with block and group as factors there was a significantly greater squared autocorrelation for the Schizophrenia (0.16) than control (0.11) group, F(1,36) = 6.35, p = .016, but no main effect of block or interaction between block and group (Fs < 1). When we fit higher-order autoregressive models (i.e., models allowing for lag two and higher autocorrelations) the same pattern of results was found for lag-one autocorrelations and no significant effects were found for higher-order autocorrelations.
On average, the lag-one correlation was positive for the Schizophrenia group (0.03), indicating a tendency to repeat responses, whereas in the control group it was negative (-0.03) indicating a tendency to alternate responses. However, the signs of the correlations were variable within groups, so the main effect group on correlations was not significant, F(1,36) = 2.74, \( p = .11 \). Three patients had autocorrelations less than -0.1, indicating a response-alternation pattern, and 8 had autocorrelations greater than 0.1, indicating a repetition pattern. Four controls also had autocorrelations less than -0.1, but none had autocorrelations greater than 0.1.

### 2.7 Discussion

Although there were trends for both slower and less accurate responding in the Schizophrenia than control group, neither difference was significant, and corresponding effect sizes (\( \eta^2 \)) were small (0.027 and 0.049 respectively). These results might be taken to indicate that our simple task and calibration procedure successfully addressed confounding of the group factor by motivational differences that might have affected other choice RT studies of Schizophrenia (Joyce & Huddy, 2004). Another interpretation is that the separate analyses of accuracy and mean RT lacked sufficient power to detect the underlying group effect because it was spread over the two measures and other aspects of performance. We examine below whether a model-based analysis – which simultaneously captures all of these aspects of performance – is more sensitive to the group effect.

In contrast to mean RT and accuracy, sequential effects were sufficiently strong by themselves to achieve significance (\( \eta^2 = 0.15 \)). The analysis of squared lag-one autocorrelations indicated a stable tendency throughout the experiment for responses in the Schizophrenia group to be more influenced by the immediately past response than responses in the control group. Sequential effects in patients mainly manifested as a tendency to repeat
the last response, but some patients and also some controls displayed a tendency to alternate responses.

There is a long history of studies examining stimulus and response repetition and alternation effects in healthy participants (e.g., Bertelson, 1961; Kirby, 1976). Although these effects are often small, there is a reliable bias to repeat responses, or make repeat responses faster, when the response-to-stimulus interval is less than 0.5s, and a bias to alternate responses, or make alternate responses faster, when it is longer (Soetens, Boer, & Hueting, 1985). Our response-to-stimulus was around 2s on average, so the general tendency to an alternation bias in our controls is to be expected, but the repetition-bias in our Schizophrenia group is unusual. In a description reminiscent of Zubin’s (1975) explanation of the effect of prior events on simple RT in Schizophrenia, Soetens et al. attributed repetition effects to “decaying memory traces related to the structural pathway of the reaction process” (p. 598). With a compatible stimulus-response mapping such as the one we used, repetition effects have been localized in response-related stages of processing (Soetens, 1998). Our results support the contention that the decay of memory traces in the response stage was abnormally slow for many of the participants in our Schizophrenia group.

In Brown et al.’s (2008) model of absolute identification, repetition effects were mediated by the decay of activation in evidence accumulators between trials. When the decay was insufficient to return activation to baseline, the accumulator corresponding to the previous response began with a head start, causing a repetition bias. In the LBA model that we fit in the next section, accumulation is linear, so this sort of bias will be equivalent to having a reduced threshold parameter for the accumulator corresponding to the last response. To test this explanation we fit the data broken down by the last response type (i.e., left or right) and allowed this factor to bias the LBA threshold. The corresponding test for the DDM, which as we explain below assumes a single accumulator with activation that starts between lower and upper threshold corresponding to each response, allowed the last-response factor to
bias the DDM’s starting-point parameter. We now report the results of these model-based analyses.

### 2.8 Model-Based Analysis

We fit the models using quantile-maximum-probability estimation (Heathcote & Brown, 2004; Heathcote, Brown & Mewhort, 2002), which minimizes a measure of misfit called the deviance that is calculated based on RT distribution quantified by calculating the 10\(^{th}\), 30\(^{th}\), 50\(^{th}\) (median), 70\(^{th}\) and 90\(^{th}\) percentiles of the RT data. A set of 128 DDM models and 256 LBA models were generated as described in Donkin, Brown and Heathcote (2011).

These models were simplifications of a most flexible or “top” model that allowed model parameters to vary with experimental factors, and in the case of the LBA model with factors designating the different accumulators (see Table 2).

#### Table 2. Definitions of model factors.

Experimental factors describe the experimental design, accumulator factors apply only to the LBA model and differentiate the two accumulators either according to the response they represent or the match between the stimulus and the response they represent.

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difficulty (D)</td>
<td>Experimental</td>
<td>left = left motion, right = right motion</td>
</tr>
<tr>
<td>Stimulus (S)</td>
<td>Experimental</td>
<td>left = left motion, right = right motion</td>
</tr>
<tr>
<td>Last Stimulus (L)</td>
<td>Experimental</td>
<td>left = left motion, right = right motion</td>
</tr>
<tr>
<td>Response (R)</td>
<td>Accumulator</td>
<td>left = left motion, right = right motion</td>
</tr>
<tr>
<td>Match (M)</td>
<td>Accumulator</td>
<td>true = matches, false = mismatches stimulus</td>
</tr>
</tbody>
</table>

When fitting a model, choices have to be made about how parameter estimates are influenced by experimental factors. These decisions are made in part based on the meaning of the parameters and in part on convention. There are also practical considerations; allowing the parameter specification too complex can result in an unmanageably large number of parameters to estimate and/or “over-fitting”: small improvements in fit that result in
parameter estimates that vary in meaningless ways in order to accommodate small random variations in the data.

We addressed over-fitting using the Akaike Information Criterion (AIC: Burnham & Anderson, 2004), which adds to the misfit (deviance) measure a complexity penalty proportional to the number of model parameters\(^1\). We also examined results with the Bayesian Information Criterion (BIC), which has similar properties to AIC but imposes a stronger complexity penalty, and so prefers simpler models (Burnham & Anderson, 2004). Conclusions were very similar, with the LBA being preferred over the DDM, but for both models very simple variants were selected with no experimental factor effects for the DDM and only the match factor affecting the drift rate for the LBA. The BIC models fit significantly worse than the AIC models and clearly did not fit the data in plots like Figures 6 and 7 so we report the more plausible AIC-based results. Adding parameters must improve model fit (i.e., reduce deviance), but if the improvement is small it will be outweighed by the penalty and so AIC will select the simpler model. The model that strikes the best balance between complexity and a good fit among the model variants will have the smallest AIC. AIC values can be used to test which model performs the best; a smaller AIC by 10 or more indicates a strong preference, 3-10 substantial evidence and less than 3 indicates an equivocal result.

\[ \text{2.8.1 The Drift-Diffusion Model (DDM)} \]

Figure 4 describes the DDM model and Table 3 names its parameters. The RT predicted by the model is the sum of decision time – the time from when evidence starts accumulating until that evidence first crosses a threshold – and non-decision time. 

\[ \text{\footnote{1 We also examined results with the Bayesian Information Criterion (BIC), which has similar properties to AIC but imposes a stronger complexity penalty, and so prefers simpler models (Burnham & Anderson, 2004). Conclusions were very similar, with the LBA being preferred over the DDM, but for both models very simple variants were selected with no experimental factor effects for the DDM and only the match factor affecting the drift rate for the LBA. The BIC models fit significantly worse than the AIC models and clearly did not fit the data in plots like Figures 4 and 5 so we report the more plausible AIC-based results.}} \]
decision time is the sum of the time to encode the stimulus and the time to produce the response corresponding to the decision. A single unit accumulates the difference in evidence favouring a left response minus evidence favouring a right response (i.e., positive evidence favours left and negative right) with expectation potentially causing a bias towards one stimulus or the other by adding a constant (the “drift criterion”, which can be either positive or negative) to the difference (Ratcliff & McKoon, 2008; Starns, White & Ratcliff, 2010). If the evidence total reaches the upper threshold a left decision is made and if it reaches the lower threshold a right decision is made. The evidence total at the start of accumulation reflects response bias (i.e., and expectation about what the stimulus will be before seeing it). Unbiased responding corresponding to a starting point half way between the two thresholds.
Figure 4. The Drift-Diffusion Model (DDM) for a left vs. right decision. U() indicates a uniform distribution and N() a normal distribution.

Even when making responses under identical conditions human RT varies considerably from trial to trial (Luce, 1986). In the DDM RT varies because of the effects of four different types of noise. The primary source is moment-to-moment noise with a normal distribution, which causes the irregular pattern of accumulation illustrated in Figure 4. This type “diffusive” noise is a definitional characteristic of diffusion models, and was the only source in the earliest versions (e.g., Stone, 1960)\(^2\). The remaining three types were added to accommodate experimental findings (Ratcliff, Gómez & McKoon, 2004; Ratcliff & Rouder, 2001).

\(^2\)In both the DDM and LBA one accumulation-process parameter must take a fixed value in at least one condition in order to identify parameter estimates (Donkin, Brown & Heathcote, 2009). For the DDM we made the conventional choice of fixing the diffusive noise standard deviation to 0.1 in all conditions. For the LBA we fixed the rate standard deviation to one for the mismatching accumulator in one condition.
The mean rate of evidence accumulation varies from trial to trial according to a normal distribution, reflecting factors such as fluctuations in attention or stimuli between nominally equivalent trials. The starting point varies from trial to trial according to a uniform distribution, reflecting bias caused by factors such as the response made on the last trial. Non-decision time varies randomly from trial to trial according to a uniform distribution.

Table 3. Definition of Drift-Diffusion Model (DDM) parameters (two left columns). The “Top Model” column indicates parameter estimates are allowed to vary with the factors* (see Table 2) in the top model. An entry of 1 in the final column indicates a single value was estimated for all combinations of factor levels. The number of model variants estimated by Donkin et al.’s (2011) method equals $2^n = 128$, where $n = 7$ is the number of factors in the table. The final column specifies factors in the model selected by AIC summed over participants.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Top Model</th>
<th>AIC Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$</td>
<td>Response caution</td>
<td>L</td>
<td>1</td>
</tr>
<tr>
<td>$v$</td>
<td>Mean rate of evidence accumulation</td>
<td>L, S, D</td>
<td>S, D</td>
</tr>
<tr>
<td>$s_v$</td>
<td>Mean rate standard deviation</td>
<td>S, D</td>
<td>S, D</td>
</tr>
<tr>
<td>$z$</td>
<td>Mean accumulation starting point</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>$s_z$</td>
<td>Range of start-point distribution</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$t_{cr}$</td>
<td>Mean non-decision time</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$s_t$</td>
<td>Range of non-decision time distribution</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

*Difficulty (D), Stimulus (S), Last Stimulus (L), Response (R), and Match (M).

Table 2 also shows the factor-influence choices we made for the top DDM model. Each participant’s data was fit separately and we allowed 19 parameters to accommodate the approximately 290 data points per participant. Only the rate parameters, which model stimulus effects, were allowed to vary with stimulus type (left vs. right motion) and difficulty (easy vs. hard) factors. The stimulus on the last trial was allowed to potentially cause bias both through decision-process related parameters, response caution and response bias, and through the mean drift rate, reflecting effects on the drift criterion. For all other parameters a single value was estimated for all conditions.
2.8.2 The Linear Ballistic Accumulator (LBA) Model

Figure 5 describes the LBA model and Table 4 names its parameters. There are three major differences from the DDM. First, accumulation is ballistic, meaning that there is no moment-to-moment noise. Second, there is no non-decision noise; this is not a fundamental assumption, but rather is based on empirical observation that allowing non-decision noise is not necessary as it has been found to be for the DDM (Ratcliff et al., 2004). Normal and uniform trial-to-trial noise in rates and start-points noise, respectively, are assumed. These are the sole causes of variability in RT, with the same interpretations as in the DDM. Third, there is one accumulator for each possible choice. Each independently accumulates evidence favouring its choice, and a response corresponding to that choice is made if it is the first to reach its threshold. Each accumulator has its own parameters for the rate mean and standard deviation, range of start point noise and threshold, so the LBA tends to have more parameter estimates than the DDM, although parameters can be assumed to be the same over accumulators. Differences in thresholds – as specified by the “response” factor in Table 2 – cause response bias, with unbiased responding corresponding to equal thresholds across accumulators. When accuracy is above chance the rate for the matching accumulator (e.g., the left accumulator when viewing a left-moving stimulus) is greater than that for the mismatching accumulator. The “match” factor (see Table 2) is used to specify such differences. The rate for an accumulator determines how quickly its corresponding response is made, whereas differences in rates between accumulators mainly affect accuracy (e.g., accurate responding occurs when there is a large difference between matching and mismatching accumulators).
Figure 5. The Linear Ballistic Accumulator (LBA) model for a left vs. right decision. $U()$ indicates a uniform distribution and $N()$ a normal distribution.

Table 4 also shows the factor-influence choices we made for the top LBA model, which has 29 estimated parameters. The threshold can vary with the response factor, allowing for an overall response bias, and the last-trial factor, allowing for a bias for or against the last response. These assumptions are analogous to the assumptions about the DDM caution and
start-point parameters. The assumptions about the rate mean and standard deviations are also the same as for the DDM, with the extra “match” factor allowing for differences between accumulators. The same values of the start-point variability and non-decision time parameters were estimated for all experimental conditions and accumulators. Note that in Figure 5 the range of start point variability is denoted by $A$. As shown in Table 4, we estimated $a = b/A$, i.e., the range as a proportion of the threshold (note $0 \leq A \leq b$ so $0 \leq a \leq 1$). This meant that start-point variability increased in proportion to the threshold. This proportionality assumption held to a good degree even when we did not enforce it so we chose this parameterization to simplify the model.

Table 4. Definition of LBA parameters (two left columns). Note that $a = A/b$, where $A$ is the range of start-point variability. The “Top Model” column indicates parameter estimates are allowed to vary with the factors* (see Table 2) in the top model. An entry of 1 in the final column indicates a single value was estimated for all combinations of factor levels. Note that the number of model variants estimated by Donkin et al.’s (2011) method equals $2^{n-1} = 256$, where $n = 9$ is the number of factors in the table. One is subtracted from $n$ because even in the simplest model the mean rate varied with $M$ to allow for above chance responding (the DDM model always allows for this because its rate is the difference between evidence for each response). The final column specifies factors in the model selected by AIC summed over participants.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Top Model</th>
<th>AIC Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b$</td>
<td>Response threshold</td>
<td>R, L</td>
<td>R, L</td>
</tr>
<tr>
<td>$a$</td>
<td>Proportional start-point variability range</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$v$</td>
<td>Mean rate of evidence accumulation</td>
<td>L, S, D, M</td>
<td>D, M</td>
</tr>
<tr>
<td>$s_v$</td>
<td>Rate standard deviation</td>
<td>S, D, M</td>
<td>D, M</td>
</tr>
<tr>
<td>$t_{er}$</td>
<td>Mean non-decision time</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

*Difficulty (D), Stimulus (S), Last Stimulus (L), Response (R), and Match (M).

2.8.3 Results

The overall fit of the top LBA model was much better than that of the DDM model as reflected by deviance values summed over participants (D) of 2142 and 3042 respectively. This might be expected given the LBA model has many more estimated parameters (29 vs.
19). However, the LBA model with the best AIC summed over participants (3513) had only 13 parameters, and still fit substantially better ($D = 2525$) than the top DDM model. Its AIC was also substantially less than for the DDM model with the smallest AIC (4299).

Comparing the best AIC models, the LBA did better than the DDM for patients ($\text{AIC} = 1721$ vs. 2231). For controls the LBA did slightly worse than for patients, but the DDM did better for controls than patients, although the DDM was still worse than the LBA ($\text{AIC} = 1793$ vs. 2068). On an individual basis AIC favoured the LBA for 74% (14/19) of patients but only 53% (10/19) of controls. However, not much of the evidence was strong (i.e., a difference of greater than 10) favouring the DDM (0/5 for patients and 3/9 for controls), whereas most was strong for the LBA (13/14 for patients and 9/10 for controls).

Deviance values cannot be used to test between the DDM and LBA, but they can be used to test between variants within a model, where a difference if deviance has a $\chi^2$ distribution with degrees of freedom equal to the difference in number of parameters. These $\chi^2$ tests confirmed the AIC selection for the LBA model, with the decrease in fit from the top to AIC model not being significant, $\chi^2(646) = 383$, $p = 1$. Also, there was clear evidence of over-fitting in the top model, which had a number of implausible parameter estimates. In contrast, the decrease in fit for the DDM model was highly significant, $\chi^2(342) = 497$, $p < .001$. In light of these findings we focus on the top DDM model (with 19 parameters per subject) and the AIC-selected LBA model (13 parameters per subject) for further analysis.

The fit of these models is displayed in Figures 6 and 7. Figure 6 shows the observed and predicted error rates for the DDM (left column) and LBA (right column) for controls (top row) and participants (bottom row). The DDM has more misfit than the LBA mainly because of an inability to accommodate the effect of the last response. This is particularly clear for the patients, who show higher error rates when the current stimulus mismatches the last response, caused by a tendency to repeat the last response that is captured by the LBA. Note, however,
that the last-response effect was not the only cause of better performance for the LBA. We also fit models without breaking down the data by last-response. The LBA still fit better than the DDM (D = 1358 vs. 2066) and the LBA variant with the best AIC was selected over the DDM variant with the best AIC (2465 vs. 2947).

Figure 6. Error rates as a function of difficulty and current and last stimulus (left or right motion) with superimposed model fits (left column DDM model, right column LBA model). Error bars indicate 95% within-subject confidence intervals (Morey, 2008).

Figure 7 shows the distribution of correct RT by displaying the 10th percentile (i.e., a measure of the fastest responses), the 50th percentile (i.e., the median) and the 90th percentile (i.e., a measure of the slowest responses). For clarity the 30th and 70th percentiles, which were also used in fitting, are not displayed, but show the same trends. Once again the LBA model fits better, but both models provide a fairly good account overall, capturing, for example, the positive skew characteristic of RT distributions as evidenced by a greater gap between the median and 90th percentile than between the median and 10th percentile. We do not display
analogous results for errors as, being less frequent, percentile estimates had quite wide 95% confidence intervals. Both models made similar predictions that fell within these intervals and captured the general tendency for slower error than correct responses.

Figure 7. RT distribution (10th, 50th and 90th percentiles) for correct responses as a function of difficulty and current and last stimulus (left or right motion) with superimposed model fits (left column DDM model, right column LBA model). Error bars indicate 95% within-subject confidence intervals (Morey, 2008).

2.8.4 Parameter Analysis

Given the inability of the DDM to fit the last-response effect and the model-selection results favouring the LBA, we provide the detailed results of an analysis of the DDM model’s parameters in supplementary materials (Appendix A) and present only an overview here. As expected the effect of stimulus difficulty was explained by a drift-rate difference. The mean drift rate in the Schizophrenia group was significantly less that for the control group in the
AIC selected model, but was only marginally significant in the top model. Last-response has a significant effect on the starting point parameter, but it indicated a bias towards alternation rather than repetition and did not interact with group, again indicating that the DDM was relatively insensitive to sequential effects. The AIC-selected LBA model displayed a larger set of significant effects than the DDM model, including group effects in both rates and thresholds. We address the group effects after first discussing the effects common to both groups.

Reflecting the fact that accuracy was above chance, the rate of the matching accumulator (1.7) was greater than the rate of the mismatching accumulator (-1.2), $F(1,36) = 60, p < .001$. The rate standard deviation for the mismatching accumulator (1.1) was greater than for the matching accumulator (0.8), $F(1,36) = 9.4, p = .004$, as has been found in other LBA applications (e.g., Heathcote & Love, 2012; Rae et al., 2014). The difference between matching and mismatching accumulators was larger for easy (3.7) than hard (2.2) stimuli, $F(1,36) = 9.4, p = .004$, consistent with higher-quality evidence, and hence greater accuracy, for easy than hard stimuli.

As evidence quality is also a function of the rate standard deviation it is useful to calculate a quantity analogous to the signal-detection theory discriminability measure ($d'$). A higher rate standard deviation will more often cause errors due to increasing the number of trials on which mismatching evidence exceeds matching evidence. The $d'$ measure takes this into account by expressing the difference between matching and mismatching means in units of the pooled standard deviation:

$$d' = (v_{match} - v_{mismatch})/\sqrt{(s_{\text{match}}^2 + s_{\text{mismatch}}^2)/2}.$$  

The $d'$ for easy stimuli (5.5) was significantly greater than for hard stimuli (3.6), $F(1,36) = 15.2, p < .001$. Finally, consistent with the overall right response bias noted earlier, there was a lower threshold estimate for the right (2.1) than left (2.3) accumulator, $F(1,36) = 5.1, p = .03$. 
Turning to the group effects, the matching vs. mismatching difference was larger for controls (3.8) than patients (2.1), F(1,36) = 6.7, \( p = .014 \). This was mainly due to the mismatching rate being much smaller for controls (-2.3) than patients (-0.2), and to a lesser degree because patients had a higher matching rate (2) than controls (1.5). Controls also had a much larger \( d' \) (6.2) than patients (2.9), F(1,36) = 8.8, \( p = .005 \). Patients had a larger threshold than controls (2.8 vs. 1.6), F(1,36) = 4.45, \( p = .04 \), but did not differ significantly in non-decision time (0.24s vs. 0.22s), \( F < 1 \).

In contrast to the DDM, the LBA was sensitive to the effect of the last response. The top LBA model allowed the last response to affect both rates and threshold, but AIC indicated that the last-response effect was mediated by threshold difference only. To form a model-based index of perseverance (i.e., the tendency to repeat the last stimulus) we first calculated indices of response bias. A bias towards the left response occurs when the left accumulator has a lower threshold than the right accumulator, and vice versa for a right bias. Left response bias (i.e., \( b_R - b_L \)) when the last response was left as summed with right bias (i.e., \( b_L - b_R \)) when the last response was right to form a measure of perseverance. For both components a positive values indicate a response bias towards the last response, so their sum is the overall strength of the model’s tendency to be biased towards the last response.

Recall that lag-one autocorrelations are positive when responses tend to be repeated. In the overall sample the model-based perseverance measure correlated highly with the lag-one autocorrelations, \( r = .73, t(36) = 6.4, p < .001 \). The correlation was almost entirely due to patients, \( r = .83, t(17) = 6.1, p < .001 \), and was non-significant in controls, \( r = .16, t(17) = 0.67, p = .16 \).

2.9 Discussion

For both the LBA and DDM AIC model selection confirmed mediation of the difficulty effect by rate mean and variability parameters. The stimulus type (left vs. right
motion) affected both of these parameters for the DDM but not LBA, which accommodated stimulus differences through response bias. AIC selected an effect of last response on bias for both models. However, even the most flexible top DDM model with 19 parameters could not capture the last-response effect on accuracy, whereas the LBA captured it quite well even in the simpler 13 parameter AIC-selected version. Both models gave a good account of the distribution of correct RT. However, given the differences in fit to accuracy, and strong evidence based on AIC selecting the LBA over the DDM – particularly for the Schizophrenia group where sequential effects were strongest – our further discussion focuses on the LBA.

Although group effects on accuracy and mean RT did not achieve significance, there were significant group differences in LBA parameters that affect both RT and accuracy. When the effects of the rate means and standard deviations on accuracy were quantified by a d’ measure, the group effect was actually larger than the analogous difficulty effect and highly significant ($\eta^2 = 0.2$). However, the group effect on accuracy was not as great because the threshold was larger in the Schizophrenia than control group ($\eta^2 = 0.11$). A higher threshold reduces the effects of random biases caused by start point noise, and hence it increases accuracy, countering to some degree the deleterious effects of the patients’ lower d’.

Higher thresholds also slow responding, which explains why patients correct responses were slower than controls even though they had a slightly higher rate for the matching accumulator, which is responsible for the speed of correct responses. Hence, the LBA model attributes slowing in the Schizophrenia group to quite a different cause that the DDM, which attributes it to the rate of evidence accumulation ($\eta^2 = 0.1$). The LBA explanation is reminiscent of Ratcliff and colleagues’ findings for the effect of aging for stimuli where perception is degraded in the older group. That is, the overall group effect is
explained by both threshold and rate effects, although in the present case there was no
evidence for a slowing in non-decision time as there is with aging.

A second point of difference from the effect of aging concerns sequential effects
(although it is possible that these exist in aging and simply have not been investigated).
Sequential effects, which as a function of individual difference could manifest either as a bias
to repeat the last response and a tendency to alternate responses, was explained by differences
in LBA thresholds between the accumulators corresponding to each response. This was
particularly the case for the Schizophrenia group, where the model-based threshold effect
accounted for almost two thirds of the individual variation in the directly observed
autocorrelation-based measure of sequential effects. In the General Discussion we discuss the
implications of this novel and unexpected effect and its clear relationship to related sequential
effects that were the focus on much of the initial work on slowing of simple RT in
Schizophrenia.

2.10 General Discussion

It is widely acknowledged that Schizophrenia causes deficits in a variety of sensory
specifically showed that RDK motion detection is impaired in patients with Schizophrenia
but intact in their relatives and bipolar patients. Surprisingly then, although our Schizophrenia
group were a little less accurate and had a somewhat larger mean RT that our control group,
neither effect achieved significance. These results might be taken to indicate that our simple
task and calibration procedure successfully addressed confounding of the group factor by
motivational differences that might have affected other choice RT studies of Schizophrenia
(Joyce & Huddy, 2004).

Another interpretation, which was supported by our model-based analysis, is that the
separate analyses of accuracy and mean RT lacked sufficient power to detect the underlying
group effect because it was spread over the two measures and other aspects of performance. The model-based analysis – which simultaneously captures all of these aspects of performance – was more sensitive to the group effect. For the DDM, at least in its AIC-selected version, the Schizophrenia group had a significantly lower rate of evidence accumulation than the control group. A lower rate has multiple effects, decreasing accuracy and causing slowing and increased variability in RT. As significant group difference in rate was obtained by taking account of all of these effects together.

The LBA was also more sensitive than separate analyses of accuracy and mean RT, but painted a more nuanced and accurate picture of the group differences not only in terms of sequential effects but also in terms of speed and accuracy. When the combined effects of the rate means and standard deviations were quantified by a d’ measure, the group effect was highly significant. Indeed, it was actually larger than the analogous difficulty effect on d’. Difficulty significantly effected accuracy, but the group effect did not, because thresholds were larger in the Schizophrenia than control group. In the LBA a higher threshold reduces the effects of random biases caused by start point noise, and hence it increases accuracy, countering to some degree the deleterious effects of the patients’ deficits related to evidence accumulation rates.

Higher thresholds also slow responding, but patients’ correct responses were not significantly slower than controls because they had a higher rate for the accumulator that matched the stimulus, which is largely responsible for the speed of correct responses. The latter result, and the finding that the Schizophrenia group had an increased rate for the accumulator corresponding to the incorrect response, is at odds with Kappenman et al.’s (2012) conclusion based on lateralized readiness potentials. Regardless, it is clear that the LBA model explains slowing in our Schizophrenia group in quite a different way to the DDM, which attributes it to the rate of evidence accumulation. The LBA explanation is reminiscent of Thapar, Ratcliff and McKoon’s (2003) findings for the effect of aging in a
case where perception of the task stimuli is known to be degraded in the older group (masked letter discrimination). That is, our overall group effect is explained by both threshold and rate effects, although in the present case there was no evidence for a slowing in non-decision time as there is with aging.

A second point of difference from the effect of aging concerns sequential effects, although it is possible that these exist in aging and simply have not been recognized. Although Schizophrenia is associated with psychomotor slowing in complex sequence production, this is largely in the planning component (Jogems-Kosterman, Zitman, Van Hoof & Hulstijn, 2001; Kim, Lee, Choi & Goh, 2009). As planning is not a factor in the simple button press response required in our study, this is perhaps unsurprising.

The increased threshold in the LBA, the decreased rate of evidence accumulation in the DDM, an increased RT standard deviation in the Schizophrenia group, and our meta-analysis confirmed a quite strong RT effect, although this was based on a small number of studies. One of these, Rentrop et al. (2010), suggested that an increased RT variability in Schizophrenia could reveal unstable information processing due to amplified noise in the fronto-cerebellar circuits. They fit their correct RT data with ex-Gaussian distribution using Heathcote’s (1996) methods and reported only a small increase in the mean but a much larger increase in skew (see also Fassbender, Scangos, Lesh & Carter, 2014; Kieffabe et al., 2006). In simple RT for eye movements Smyrnis et al. (2009) reported a similar effect on variability and not the mean, although, in contrast to manual simple RT, a failure to find slowing in mean RT is common for eye movements (Gale & Holzman, 2000).

Smyrnis et al. (2009) fit their data with the LATER model (Carpenter & Williams, 1995), which makes the same assumptions as for a single LBA accumulator except that no start-point noise was included. They found a significant increase in the evidence accumulation rate standard deviation for their Schizophrenia group, with no significant difference in the mean rate from their control group. For our LBA fits, in contrast, there was
no significant group effect on the rate standard deviation. The divergent pattern of results
could be due differences between a choice RT paradigm with manual responses and a simple
RT paradigm with saccadic responses. However, it would be interesting to also investigate in
future research the possibility that start point noise and sequential effects may have a role to
play in the latter paradigm.

The early history of the study of slowing in Schizophrenia focused on the effect on
simple RT of prior events, particularly the modality of the stimulus for the previous trial or a
signal warning of the imminent onset of the stimulus for the upcoming trial. Zubin (1975)
proposed that these sequential effects occur because prior events leave behind facilitatory or
inhibitory neuronal traces that tend to last longer in Schizophrenia than in healthy groups.
Perhaps the most surprising, and certainly unanticipated, outcome of our choice RT
experiment was the presence of significant sequential effects in the form of a response bias
caused by the response made in the last trial. In the main individuals in our Schizophrenia
group were perseverant, displaying a tendency to repeat the last response, although there was
substantial individual variation with some patients, and some control participants, displaying
a tendency to alternate responses.

In a description reminiscent of Zubin’s (1975) explanation, Soetens et al. (1985)
attributed repetition effects in healthy participants – for whom they occur only when the gap
between trials is much shorter than in our experiment – to “decaying memory traces related to
the structural pathway of the reaction process” (p. 598). With a compatible stimulus-response
mapping such as the one we used, repetition effects have been localized to response-related
stages of processing (Soetens, 1998). Our results support the contention that the decay of
memory traces in the response stage was abnormally slow for many of the participants in our
Schizophrenia group.

When evidence is accumulated linearly, as it is in the DDM and the LBA model, a
bias caused by the previous trial (i.e., the starting point for evidence accumulation on the
current trial) is equivalent to an effect on the threshold amount of evidence required for a response. Our modelling revealed that tendencies to both repeat and to alternate responses were explained by differences in LBA thresholds between the accumulators corresponding to each response. That is, where a repetition preference was observed the threshold for the accumulator corresponding to the last response was lowered, whereas when an alternation preference was observed the threshold for the other accumulator was lowered. These effects were particularly marked for the Schizophrenia group, where the threshold changes accounted for a remarkably high proportion (almost two thirds) of the individual variation in an autocorrelation measure of sequential effects.

The DDM, in contrast, was relatively insensitive to these sequential effects, which was a major factor in it not fitting the data as well as the LBA, although even when sequential effects were neglected it still performed worse than the LBA. Further research is required to determine why the models differ in this way, but one likely reason is that the large effects of moment-to-moment noise, which is present in the DDM but absent in the LBA, had washing out bias effects on start points. The sequential effects that we observed, although to our knowledge novel in a rapid RT tasks, whether of the simple or choice type, have been observed in more complex tasks such as Wisconsin Card Sorting Test (WCST), where Schizophrenia patients tend to perseverate longer than controls on the same card-sorting rule (e.g. Abbruzzese, Ferri, & Scarone, 1996; Li, 2004). Similarly in tasks requiring guessing about random stimuli there is a tendency to perseverate with the same guess about random stimuli (e.g., Lyon, Mejsholm, & Lyon, 1986; Loyon & Gerlach, 1988) and to have difficulty generating random responses (Hintze, Bebenek, Kuhn-Dymecka, Wronska, & Wciorka, 2006; Morrens, Hulstijn, Lewi, Hert, & Sabbe, 2006). Cattapan-Ludewig et al. (2008) reported both a higher proportion of both highly predictable and highly unpredictable sequences of guesses. In perhaps the closest analogue to our findings Yohev et al. (2003) had participants make choices where the stimulus changed but the correct answer remained the
same from trial to trial until a sequence of correct answers was given. Higher negative symptoms were associated with perseveration and higher positive symptoms with a tendency to switch responses too often. We did not find any significant correlations between symptoms and sequential effects (see Appendix B), but our results do suggest that a stronger focus on sequential effects in rapid choice tasks could be fruitful for future research.

2.11 References


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2.12 References for Meta-analysis


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3. Extended Discussion

The purpose of the extended discussion is to further explore and review the findings described in the manuscript. The aims of the study are presented and specific findings are discussed in further detail in context of relevant literature. Finally, strengths and limitations of the present study, as well as directions for future research are discussed.

3.1 The present study

The aim of the present study was to investigate the performance of individuals with Sz on a CRT task that requires fast decision-making. As mentioned in the extended literature review, individuals with Sz have been consistently documented to display significantly slower and less accurate responding on a variety of RT paradigms (e.g. Nuechterlein, 1977) and have also been found to display greater RT variability compared with control participants (e.g. Rentrop et al., 2010). The research studies reviewed have typically included CRT paradigms that yield high accuracy rates across groups (close to ceiling levels), so the current study manipulated task complexity to examine performance on a relatively difficult CRT paradigm. A meta-analysis was completed to better understand the common findings in the literature regarding the speed and accuracy of CRT performance in Sz populations relative to controls. In addition modelling analyses were also completed, by fitting the data to the Drift-Diffusion Model (DDM; Ratcliff & Mckoon, 2008) and the Linear Ballistic Accumulator (LBA; Brown & Heathcote, 2008) model. An advantage of evidence-accumulation models is that they can provide a complete characterization of choice behaviour, such as not only accounting for mean RT and accuracy, but also the full distribution for each choice. To our knowledge, this approach has not been previously utilized to investigate CRT performance in Sz populations and has the potential to uncover further underlying variables in speeded decision-making.
3.2 Discussion of the findings

3.2.1 Results of the meta-analysis

The results from the meta-analysis indicate a highly consistent pattern of control groups performing significantly faster relative to Sz groups, with this effect being true separately for inhibition, lexical, and non-lexical task groups. Accuracy was found to be close to ceiling in almost most cases of studies reviewed and was found to be significantly less for the Sz group compared with controls. These results support the earlier hypotheses that a systematic pattern of slower and more error-prone performance will be observed in the Sz sample relative to the control groups. These findings fall in line with the conclusions made in the extended literature critique regarding the general patterns of slower and less accurate performance in Sz in studies using CRT paradigms. Despite the small sample size, the average standard deviation for the Sz group was found to be significantly greater than the control group average, which supports the hypothesis that a pattern of increased RT standard deviation will occur in the Sz sample. This findings are congruent with studies discussed in the extended literature review, where participants with Sz have been found to display significantly higher intra-individual variability (IIV) relative to their healthy counter-parts when completing CRT tasks (Badcock et al., 2002; Kaiser et al., 2008; Kim et al., 2009; Rentrop et al., 2010; Vinogradov et al., 1998).

The findings reported so far are consistent with slowing being mediated by lower drift rate for the participants with Sz, as this would cause both slower, more variable, and more error prone responding. This was investigated further by examining the correlation of the Sz minus control group average RT differences with the corresponding accuracy differences. If these differences were mediated by drift rate then a negative correlation would be expected, however this correlation was found to be negative, but was also small and non-significant. This led to the indication that there may be an additional factor, such as the threshold
difference that may be mediating these group differences. However, the threshold difference alone cannot explain these differences, as this would mean the Sz group would be slower due to a higher threshold but they would also be more accurate, which was not the case. However, the higher threshold in combination with the drift rate difference may better explain the pattern of these results. For instance, individuals with Sz may be attempting to compensate for the lower accuracy caused by a lower drift rate by raising their threshold, however they are not able to adequately compensate as they are still less accurate, and due to increased caution are also slower in speed. Further insights into this potential strategy are discussed in subsequent sections detailing the modelling analyses.

3.2.2 Speed and accuracy of performance

The analyses that were not model-based revealed that the Sz group were slower and less accurate that control participants, however this difference was not significant. Thus, the hypothesis that the Sz participants will display a significantly slower RT and more error-prone performance was not supported. This findings stand in contrast with previous documentations in literature of individuals with Sz displaying slower and less accurate performance compared with healthy individuals across a variety of CRT paradigms, as discussed in the extended literature review. This result is particularly surprising given that the task in the present study was designed to increase errors due to the added complexity of the chosen RDK stimulus. It has previously been documented that as task complexity increases, individuals with Sz tend to show a disproportionate decrease in their speed and accuracy compared with healthy participants (Krieger et al., 2001; 2005; Pellizer & Stephane, 2007; Venables, 1958; Woodward et al., 2014). However, these studies are referring to the introduction of additional choices as a measure of increased task complexity, and it has been previously mentioned that manipulations in response complexity as opposed to stimulus complexity is what contributes to more deficient performance in Sz (Hemsley, 1976b).
Another possible interpretation of the RT and accuracy results was that the analyses lacked sufficient power to detect the underlying group effect because it was spread over the two measures and other aspects of performance.

The results also support the hypothesis of finding increased RT standard deviation in the Sz sample relative with controls, which is consistent with previous reports detailing increased RT variability in CRT performance (Kaiser et al., 2008; Kim et al., 2009; Rentrop et al., 2010; Vinogradov et al., 1998). Furthermore, in the model fittings, a positive skew characteristic of RT distributions for the Sz group was found, evidenced by a greater gap between the median and 90th percentile than between the median and 10th percentile. This is relevant to previously reported findings of an increased proportion of particularly long RTs in Sz relative to controls (Fassbender et al., 2014; Rentrop et al., 2010; Kieffabert et al., 2006) and this has been conceptualized to indicate lapses in proactive control (Fassbender et al., 2014).

3.2.3 Model-based analyses

Although the traditional analysis did not yield significant results, the model-based analyses were more sensitive to group effects as they are able to capture all aspects of RT performance. Overall, the LBA model was a much better fit than the DDM and it produced a greater number of significant effects, including group effects in both rates and thresholds. A more in-depth analysis of DDM parameters is available in Appendix A, and one of the key findings into this model fitting was that mean drift rate was less for the Sz group relative to controls, but this was only marginally significant. Thus, the hypothesis regarding Sz participants exhibiting a lower drift rate relative to the control group is only partially support for the DDM analyses. The discussion from this point forth will focus on findings from LBA model fittings.
In the LBA model, accumulator rates describe the average speed of evidence accumulation for each response, and lower rates are associated with slower and more error-prone responding (Brown & Heathcote, 2008). If accuracy is above chance, the rate for the matching accumulator (e.g. left accumulator when viewing a left-moving stimulus) is greater than the rate for the mismatching accumulator. The larger rate difference between the matching versus mismatching accumulators suggests more accurate responding, and such a difference was found to be greater in the control relative to the Sz group. This rate difference was mainly due to the mismatching rate being smaller for controls than Sz participants, and to a lesser extent because participants with Sz had a higher matching rate than controls. When the effects of the rate means and standard deviations on accuracy were quantified by a d’ measure, the controls were found to have a much larger d’ than Sz participants. Therefore, these findings support our initial hypothesis that the Sz sample will have lower quality evidence accumulation evidence by lower drift rate estimates relative to the control group.

Participants with Sz were also found to have a higher threshold compared with controls. A higher threshold can reduce the effects of random biases caused by start point noise, and hence it can increase accuracy. Given that higher thresholds can also slow responding, this may explain why correct responses made by participants with Sz were slower than controls even though they had a slightly higher rate for the matching accumulator, which is responsible for correct responses.

The higher threshold parameter found in the Sz group is an interesting finding and will be discussed in further detail in a subsequent section. The results from the model fittings are consistent with trends for Sz participants to response less accurately and more slowly as observed in the traditional analyses, and commonly reported in the literature. However, the LBA attributes slowing to a difference cause than the DDM, which attributes slowing to lower rates of evidence accumulation. The LBA’s explanation for slowing is reminiscent of
Ratcliff and colleague’s (e.g. Ratcliff, Thapar, & McKoon, 2006) account of slowing in aging, with the overall effect being explained by both threshold and rate effects. However, in the present study there was no evidence for slowing of non-decision time as there was in aging, thus the hypothesis for increased non-decision time for the Sz group relative to controls was not supported.

3.2.4 Sequential effects

An interesting finding in the present study was that there was a significantly greater positive auto-correlation found for the Sz group relative to controls, which suggests that Sz participants were more influenced by the immediately past response. The lag-one correlation was positive for the Sz participants indicating that they had a tendency to repeat the last response, whereas controls were more likely to alternate responses evidenced by a negative lag-one correlation. The sequential effects were further confirmed in the model fittings, with the LBA being far more sensitive to the effect of the last response compared with the DDM. A model-based perseverance measure in the LBA correlated highly with the lag-one autocorrelations, and this correlation was found to be almost entirely due to the Sz group. In the LBA, the sequential effects were explained by the differences in thresholds between the accumulators corresponding to each response.

These findings indicate a perseverative pattern of responding for the Sz group with a greater likelihood of these participants repeating their previous response. Perseveration has been described to encompass both simple and complex actions and refers to the inappropriate repetition of a response or behaviour (Crider, 1997). Compared with healthy controls, individuals with Sz have been found to display difficulty in generating random responses evidenced by repetitive and stereotyped responding (Morrens, Hulstijn, Lewi, Hert, & Sabbe, 2006). For instance, on a task that presented participants with nine randomly positioned buttons and required them to press these buttons as randomly as possible, the Sz group
exhibited significantly higher perseverative responses than their healthy relatives and the
control group (Hintze, Bebenek, Kuhn-Dymecka, Wronska, & Wciorka, 2006). Similarly, on
tasks that require participants to guess where a randomly appearing stimulus will emerge on a
computer screen, unlike healthy controls who produced more varied response patterns,
participants with Sz were found to adopt a more perseverative manner in their choices (Frith
& Done, 1983; Lyon & Gerlach, 1988; Lyon, Mejsholm, & Lyon, 1986). Using a similar
task, Cattapan-Ludewig et al. (2008) described patterns of decision-making by the Sz group
as dysregulated with a greater proportion of highly perseverative and highly unpredictable
sequences of choices. The impaired ability to generate random responses or alternate
responding has been linked to deficits in executive functioning, such that the individual is not
able to inhibit the prepotent response which results in perseverative responding (Brugger,
1997; Morrens et al., 2006). This notion is very much in line with the aforementioned reports
of the profound executive functioning deficits in Sz (Bryson et al., 2001; Mahurin et al.,
1998; Morice & Delahuntry, 1996; Pantelis et al., 2003).

Furthermore, Sz participants have been found to produce greater perseverative
responding on tasks such as the Wisconsin Card Sorting Test (WCST; Heaton, 1981) (e.g.
Abbruzzese, Ferri, & Scarone, 1996; Braff et al., 1991; Everett, Lavoie, Gagnon, & Gosselin,
2001; Perry & Braff, 1998) and a measure of perseveration and switching called the
Combined Attention Test (Yogeve, Hadar, Gutman, & Sirota, 2003). Interestingly, although
individuals with Sz show a perseverative deficit on the WCST, they have been found to be
able to improve their performance when given verbal reinforcement (Everett et al., 2001) and
monetary incentives (Summerfelt et al., 1991), which led to the suggestion that in addition to
cognitive deficits, perseverative errors on the WCST may reflect motivational factors
(Summerfelt et al., 1991). Tasks such as WCST may employ additional cognitive domains
such as executive functioning, planning, attention, and working memory, and essentially
more “higher-order” cognitive domains. It can be assumed that lower level skills may the building blocks of higher-order cognitive functions. Given that sequential effects were found in the present experiment that utilized a reasonably straight-forward speeded CRT task, it is possible to speculate that the tendency to repeat the last response observed on more basic tasks, may also generalize to the more complex tasks requiring other domains. 

The disproportionate influence of preceding events in Sz has been documented in earlier studies that have investigated crossover effects in the manipulation of PI’s (Rodnick & Shakow, 1940), as well as the modality shift effect (Mowrer, 1941). It has been proposed that prior events seem to exude more influence on RT performance in Sz than in healthy individuals (Cancro et al., 1971; Zahn, Rosenthal, & Shakow, 1961; Sutton et al., 1961). This is relevant to Zubin’s (1975) proposition that prior events may leave behind facilitatory or inhibitory neuronal traces and that these tend to persist longer for those participants with Sz relative to healthy participants.

Thus, the results from the current study regarding a greater bias exhibited by the Sz participants to the previous trial seem to fall in line with available literature on the greater occurrence of perseveration in Sz. In the current study, there were no significant differences in sequential dependencies as the experiment progressed suggesting this effect was stable over time. This indicates that this result was not simply due to increasing fatigue as the experiment progressed, particularly since mental fatigue has been found to lead to increased perseverative errors and compromised executive control in cognitive tasks (van der Linden, Frese, & Meijman, 2003).

### 3.2.5 Flexibility in responding

As discussed above, the finding from the meta-analysis as well as the model fittings, lead to the suggestion that the drift rate and threshold differences in the Sz group may be able to explain the pattern of results obtained. Individuals with Sz were found to have a
significantly higher threshold in the LBA compared with healthy controls. One possible interpretation of the rates and threshold effects found in the LBA is that participants with Sz may have been attempting to compensate for the slower and less accurate evidence accumulation by raising their threshold. This may suggest some degree of flexibility or response strategy shifting, whereby an attempt was being made to trade speed for accuracy. However, such an attempt was not entirely successful as the Sz group were still somewhat slower and less accurate than the control group, but the rate and threshold results together may indicate some differences in response strategy between groups.

This result could not have been obtained simply via traditionally analyses, which highlights the utility of the modelling approach in investigating decision-making performance in Sz. The LBA model has been previously applied to provide novel insights into the speed-accuracy trade-offs in older populations. By fitting the LBA model to the data, Forstmann et al. (2011) found that when asked to respond quickly, elderly participants were less able to lower their response thresholds compared with young participants, and thus were less able to trade accuracy for speed, adopting a cautious response strategy. This cautious approach meant that the older individuals required more information prior to making a decision and displayed a reluctance to commit errors. This highlighted that slowing in older individuals was not simply due to slower evidence accumulation but due to increased thresholds.

The adoption of a strategy that attempts to trade speed for accuracy and vice versa, is not a topic that has been commonly explored in the Sz literature. Majority of the studies reviewed in the literature critique did not analyze potential speed-accuracy trade-offs explicitly. Some attempted to explore potential trade-offs by correlating RTs with errors and observing the resulting patterns (Barch et al., 1999; Fuller & Jananshahi, 1999; Koh, Scoz, & Peterson, 1977; Spitzer, Braun, Hermle, & Maier 1993; Spitzer, Braun, Maier, Hermle, & Maher, 1993; Spitzer et al., 1994). For instance, significant positive correlations between RT and error rates were argued to dispute the occurrence of speed-accuracy trade-offs in Sz
participants and healthy controls (Carter, Robertson, & Nordahl, 1992; Meiran, Levine, Meirine, & Henik, 2000). Other attempts at investigating the relationship between speed and accuracy included the calculation of an efficiency estimate (Kurtz, Ragland, Bilker, Gur, & Gur, 2001) that was said to incorporate speed and accuracy of responding into a single measure (Chan, Chen, Cheung, Chen, & Cheung, 2004). The efficiency estimate was calculated as described in Kurtz et al., (2001), and in short, a ratio was derived by dividing the number of true positives (hits) by the mean RT on correct responses, and then applying an angular transformation.

Furthermore, in a study by Ferri et al. (2012) study, an inverse efficiency measure (Christie & Klein, 1995) was used which was also described to take into account speed and accuracy. This measure was calculated by dividing median values for correct RTs by their corresponding proportion correct score, which meant that differences in RTs performance decreased if differences in accuracy were large but remained the same if accuracy was similar. Lower inverse efficiency scores indicated overall superior performance and Ferri et al. (2012) found significantly higher inverse efficiency scores in the Sz group compared with controls. However, potential speed-accuracy trade-offs were not outlined specifically, and these types of measures may not provide enough insight into the underlying elements of decision making, such as rates of evidence accumulation and response thresholds.

One possible speculation is that the current sample of individuals with Sz had some awareness of the slow and error-prone nature of their responding and attempted to overcome this by raising their response thresholds. The available literature on response flexibility in Sz has mixed findings. Holcomb et al. (2004) argued that individuals with Sz might not be able to modulate their response speed when the context demands change, such as more emphasis being placed on accuracy over speed. For healthy individuals, if the importance of accuracy over speed is highlighted, then they will typically slow their responding down in order to maximize the likelihood of accuracy (Luce, 1986), however the person with Sz may have less
capacity to compensate in high error conditions by modifying their response speed (Holcomb et al., 2004). Holcomb et al., (2004) tested sixteen people with Sz and matched healthy controls using a visual and auditory discrimination CRT task. The task comprised of eight levels of difficulty and participants were instructed to prioritize accuracy over speed. Interestingly, Holcomb et al. (2004) found that unlike healthy controls who varied their response speeds in order to increase likelihood of accuracy, participants with Sz responded similarly in terms of their RT latency across the difficulty conditions. As their error rates rose, participants with Sz did not slow their responding in order to improve their accuracy suggesting an inability to implement a more flexible responding strategy. A similar finding was reported by Schweitzer and Lee (1992) in a study investigating the differences in focused attentional resource allocation in a two-choice visual discrimination task. Three conditions were used: (1) emphasis placed on accurate responding, (2) emphasis placed on fast responding, (3) speed and accuracy were given equal priority. Schweitzer and Lee (1992) found that control participants were able to balance their attentional resources in the condition that emphasized equal importance of speed and accuracy, however the Sz participants continued to prioritize speed and continued to respond quickly despite the instructions.

On the other hand, Fuller and Jananshahi (1999) found that their sample of individuals with Sz was able to use information provided in advance in order to speed up their responding, suggesting some response flexibility. In this study, performance was compared across a simple RT task, a CRT task, and a fully cued CRT task. In the latter task, participants were provided with advance information regarding the response that will be required (e.g. “left” or “right”), so essentially they could essentially “preprogram” their response. Fuller and Jananshahi (1999) found that although participants with Sz were slower in their overall RTs and movement time across all tasks, they were actually able to use this advance information to their advantage in order to speed up their RT, and they did so in a manner
similar to control participants. This finding may be consistent with the idea that Sz participants may have some flexibility in their response strategies, such as being able to modulate their response speed. Similarly, studies on reward processing also found that participants with Sz were able to speed up their responding on trials that were associated with incentives (Mann, Footer, Chung, Driscoll, & Barch, 2013).

In regards to neurobiological correlates, the anterior cingulate cortex (ACC) activity has been associated with the occurrence of speed-accuracy trade-offs (Mulert, Gallinat, Dorn, Herrmann, & Winterer, 2003). Neuroimaging investigations have implicated the ACC in the involvement of performance monitoring, which is a key feature of cognitive control (MacDonald, Cohen, Stenger, & Carter, 2000; Mulert et al., 2003). Higher activity in the ACC has been associated with conditions in which there is a high likelihood of errors occurring (Carter et al., 1998) and has been linked to faster RT (Naito et al., 2000). In healthy individuals, increased ACC activity has been associated with faster RT but also increased error rates in an auditory CRT paradigm (Mulert et al., 2003), with the authors suggesting that increased ACC activation may be associated with speed-accuracy trade-offs occurring. Sz participants who show low levels of activity in the ACC, perform slower but also trend towards having higher error rates, whereas healthy individuals with lower ACC activity and slower performance display more accurate performance (Mulert et al., 2003). This finding is related to reports of dysfunctions and abnormalities of the ACC found in individuals with Sz relative to healthy individuals and the ability to trade speed for accuracy and vice versa (Benes, 2000; Dolan et al, 1995; Mulert et al., 2001).

Furthermore, investigations into neural correlates of model-based findings have been conducted in regards to speeded decision-making (Forstmann et al., 2008; Forstmann et al., 2010). When participants are cued for speed, modelling analyses have shown that the response threshold is lowered, so that responses become quicker but potentially less accurate.
as less evidence is accumulated before a decision is made (Bogacz, Brown, Moehlis, Holmes, & Cohen, 2006). Model-based functional neuroimaging showed that cueing for speed led to activation of the Striatum, which has been implicated in releasing motor inhibition leading to faster but possibly hasty responding (Forstmann et al., 2008). Variations in striatal activation are associated with variations in the adjustments of response thresholds derived from modelling approaches suggesting a neural correlate of the speed-accuracy trade-off (Forstmann et al., 2008). Forstmann et al. (2010) further confirmed these findings in a subsequent experiment whereby behavioural data and mathematical modelling analyses identified a relationship between striatal activation and threshold adjustments. Forstmann et al., (2010) found that individuals with stronger structural connections between the presupplementary motor area and the striatum were able to change their thresholds in a more flexible manner. Individuals with Sz have been found to have abnormal striatal activation and poor inhibitory control (Vink, Ramsey, Raemaekers, & Kahn, 2006), which suggests they may experience difficulty in flexibly adjusting their response thresholds.

### 3.2.6 Response caution

As mentioned above, the threshold parameter represents how much evidence accumulation is required before a decision is produced and can be described to signify the degree of response caution (Brown & Heathcote, 2008; Heathcote & Hayes, 2012). Given the result obtained in the Sz group in the present study having higher response thresholds in the LBA model, it may be useful to consider how this marries up with available literature regarding response caution in Sz.

Draguns (1963) described individuals with Sz, particularly those with an enduring illness, as more likely to require less evidence than control participants to make judgments about ambiguous stimuli. In a probabilistic inference task, participants who reported experiencing delusions required significantly less information prior to making a decision,
compared with non-deluded participants and healthy controls (Garety, Hemsley, & Wessely, 1991). A “jumping to conclusions” bias (Garety & Freeman, 1999) was proposed in regards to the hasty decision making style of deluded individuals with Sz which suggested that these individuals made decisions on the basis of little evidence. Hasty decision-making was even found in non-schizophrenic individuals with subclinical delusional beliefs when compared with healthy controls (Ziegler, Rief, Werner, Mehl, & Lincoln, 2008).

An example of how jumping to conclusions can manifest itself in the daily life of an individual experiencing delusions, may be a person making the assumption that they are being followed after seeing the same brand of car a few times in a day, failing to consider the alternative hypotheses that this may be a popular car brand or simple a coincidence. Interestingly, Mortiz and Woodward (2005) found that this bias is not limited exclusively to deluded participants, but that non-deluded individuals with Sz also require significantly less information than controls to make a decision. They also found that this bias was associated with a greater number of hospital admissions, querying whether it may represent a risk factor for relapse. It has been suggested that individuals with Sz employ a liberal acceptance criteria in regards to decision making, such that they have lowered decision thresholds compared with healthy controls, making their responding hastier and less flexible (Moritz & Woodward, 2004; Veckenstedt et al., 2011). These discussions in the literature are incongruent with the findings in the current study of increased response thresholds for the Sz group. However, the tasks that were used in the studies mentioned above were far more complex and required numerous cognitive processes relative to the more simplistic CRT paradigm used in the current study. Thus, comparisons between the aforementioned literature and the current results must be viewed with caution and are speculative in nature.
3.2.7 Motion perception in Schizophrenia

The stimuli used in the CRT task in the current study was an RDK, which is a visual display comprising of randomly moving dots, with a proportion of these dots moving in a coherent direction. In contrast with control participants, deficits and abnormalities in visual motion perception have been reported to occur to a significantly greater extent in Sz (Brenner, Wilt, Lysaker, Koyfman, & O’Donnell, 2003; Chen, 2011; Spencer, Sekuler, Bennett, & Christensen, 2013). Participants with Sz have been found to be less sensitive at detecting moving stimuli (Li, 2002) and perform less accurately than controls (Chen, 2011). It has been reported that individuals with Sz are particularly impaired at processing global motion, such as detecting the direction of random dots in an RDK paradigm (Chen, Nakayama, Levy, Matthysse, & Holzman, 2003). This deficit seems to apply mainly to global motion processing, with the processing of local motion stimuli (e.g. detecting the direction of a grating) being relatively unimpaired in Sz (Chen et al., 2003). Other reports have also indicated some differences in global and local processing in schizophrenia (Coleman et al., 2009), as Sz participants tend to employ a less automatic bottom-up process by focusing on individual or local details first in order to construct a larger representation of stimuli (John & Hemsley, 1992). In an experiment that involved stimuli which consisted of numbers made up of dots in a hazy background, participants with Sz were significantly more likely to see the dots first (bottom-up processing), whereas the control participants saw numbers first (top-down processing) (Bemporad, 1967). This suggests that individuals with Sz may have difficulty processing motion information from many spatial and temporal locations in order to reach their decision regarding the direction of the stimuli (Chen et al., 2003). Taking these findings into consideration, it was a surprising finding that our Sz group was only a little less accurate and had a somewhat larger mean RT than our control group, with neither effect reaching significance.
Individuals with Sz have been found to require higher levels of coherence in motion perception tasks in order to perform as accurately as controls (Chen, 2011), which is consistent with the finding in the present study, whereby a greater proportion of Sz participants required the easy condition (10% and 20% coherence in RDK stimuli) than the control group. The Sz participants were found to be slower and less accurate than controls when the common 10% coherence data was analysed, however this difference was not significant. The design of the present experiment attempted to overcome any potential floor or ceiling effects in performance by incorporating three levels of task difficulty. Nevertheless, the reported difficulties in motion perception in Sz are important to consider given that the current study utilized the RDK paradigm that encompassed such global processing requirements of detecting coherent motion. This poses the question of whether motion perception deficits in Sz may have confounded the current results.

### 3.2.8 Correlations with other measures

Analyses of covariate effects were not included in the research manuscript however are presented in Appendix B. A significant positive correlation was found between mean accuracy across groups and the WTAR. This result relates to the finding that individuals with higher general fluid intelligence have been reported to perform significantly more accurately than those with lower intelligence (Gray, Chabris, & Braver, 2003). For the Sz participants, the one significant finding was a positive correlation between mean correct RT and negative symptoms, suggesting that greater negative symptoms were associated with slower performance. Negative symptoms have previously been found to correlate significantly with mean RT in a choice RT task (Schwartz et al., 1991) and also associated with slower performance on a simple RT task (whereby a choice is not required) (Ngan & Liddle, 2000). Baxter and Liddle (1998) found that psychomotor poverty scores, which encompassed core negative symptom features, were significantly correlated with slower RT in a 2-choice RT
task. However, other findings regarding the relationship between mean RT and symptoms of schizophrenia are somewhat incongruent with the present results. Disorganization symptoms have been found to have significant positive correlations with mean RT in CRT tasks whereas negative symptoms were not (Ngan & Liddle, 2000; Minzenberg et al., 2003; Vinogradov et al., 1998). Positive symptoms of Sz were also found have significant correlations with mean RT (Minzenberg et al., 2003; Schwartz et al., 1991; Vinogradov et al., 1998).

### 3.2.9 Medication effects

Almost every individual with Sz who took part in the current study was receiving clozapine as part of his or her treatment, aside from one participant. Clozapine is an atypical neuroleptic, which is commonly used in treatment for individuals with Sz for whom conventional anti-psychotics are relatively ineffective, and thus is often reserved for individuals who have an enduring or treatment-resistant illness (Kane, Honigfeld, Singer, & Meltzer, 1988; Pickar et al., 1992). Given the medication status of the present sample, it is also important to consider any potential effects that clozapine may have on cognition and more specifically in CRT performance. Clozapine has been found to have an ameliorating effect on a broad range of cognitive functions (Buchanan, Holstein, & Breier, 1994), such as being associated with improvements in motor skills and verbal fluency (Keefe, Silva, Perkins, & Lieberman, 1999), attention (Lee, Thomson, & Meltzer, 1994; Meltzer & McGurk, 1999), and some types of executive functioning (Buchanan, Hosltein, & Breier, 1994; Meltzer & McGurk, 1999). However, the gains in performance on cognitive tests associated with clozapine are relatively small and individuals on this medication do not normalize their performance to that of healthy controls (Weiss et al., 2002).

Unfortunately, few studies exist specifically investigating the impact of clozapine on choice RT. Improvements in RT on a lexical decision task have been found at six months follow-up after the commencement of treatment with clozapine in patients with Sz, however
these results were at trend level of significance (Manschreck, Redmond, Candela, & Maher, 1999). Galletly, Clark, McFarlane, and Weber (2000) found that clozapine was associated with significant improvements in RT and accuracy of target detection in an auditory discrimination task for Sz participants, when comparisons were made before and after treatment with clozapine. However, participants remained significantly slower and less accurate than controls despite this increase. Zahn et al. (1994) found that clozapine was not associated with improvements in RT when compared with conventional neuroleptic medication or placebo. At this stage, there is not enough evidence to suggest that clozapine may yield an advantage in regards to speed and accuracy in CRT paradigms.

Furthermore, seven participants in the Sz group were reported to be on anti-depressant medication at the time of testing. Unfortunately, the extent of comorbidities such as depression was not assessed thoroughly and thus it is only speculated that those participants receiving anti-depressant medication may have been experiencing symptoms of depression. Depressed individuals have been described to perform slower than healthy controls on CRT tasks and it has been suggested that information-processing stage of response selection is impaired in depression (Azorin, Benhaim, Hasbroucq, & Passam; 1995). When healthy participants are given a single dose of fluvoxamine (anti-depressant) their RT becomes faster without decreasing accuracy (i.e. they are not simply adopting a speed-accuracy trade-off) compared to participants who are unmedicated (Hasbroucq, Riht, Blin, & Possami, 1997). It seems as though depression and anti-depressants may have opposite effects on participants employing a speed accuracy trade-off (Kalb, Dorner, & Kalb, 2006). Kalb et al. (2006) found that depressed participants had increased RTs and reduced error rates compared with controls, and that greater antidepressant doses were correlated with faster RTs but with increased errors, which may suggest changes in response thresholds from a modelling perspective. These findings suggest that anti-depressants may lead to a speed-accuracy trade-off to occur in CRT performance. Once again, the effect of anti-depressant medication on the
RT performance in the present is purely speculative at this stage, however worth considering given that our sample of Sz participants had significantly increased thresholds suggesting greater response caution.

**3.3 Strengths and limitations**

One of the strengths of the present study was that to our knowledge, model-based analyses conducted in the current study have not been previously applied to deficits in choice RT in Sz. Furthermore, we were able to expand and extend upon Schatz’ (1998) meta-analysis of differences in RT between control and Sz groups, by updating it with more recent studies and including measurements of accuracy and standard deviation.

It is important to acknowledge the limitations that exist within the current study. Firstly, although we were able to engage 19 individuals with an enduring Sz illness in a reasonable challenging experiment, this sample size is small and possible led to inadequate power for the analyses to detect underlying group effects, given that many results were at trend levels of significant. Furthermore, the control and Sz groups were significantly different in their attained level of education, LNS scores (measure of working memory), and scores on the WTAR (a measure of premorbid intelligence). It is no surprise that the participants with Sz were found to have significantly lower educational levels given the extensive impacts that cognitive deficits in Sz have been reported to have on occupational functioning, such as participation in study, employment, social interactions and community activities (Aubin et al., 2009; Brekke et al., 1993; Green, 1996; Milev et al., 2005). The age of onset of Sz tends to be in the late teenage years or young adulthood which can cause significant interruptions in the person’s ability to attain educational or developmental milestones (APA, 2013). Cognitive declines have been found to precede the emergence of clinical symptoms (Caspi et al., 2003; Eastvold et al., 2007) so disruptions during those formative years may occur prior to the illness even being detected.
Higher education has been associated with better performance on a CRT task that requires executive functioning (Tun & Lachman, 2008) and attention (Le Carret et al., 2003), and has been linked to reduced cognitive decline compared with lower education levels (Bosma, Boxtel, Ponds, Houx, & Jolles, 2003). Furthermore, measures of higher psychometric intelligences have been found to be significantly associated with faster performance on CRT tasks (Neubauer & Knorr, 1997) and increased speed of information processing (Sheppard & Vernon, 2008; Vernon, 1983). In one study, participants completed a CRT task that aimed at separating the four elementary cognitive processes (Smith, 1980): stimulus perception, stimulus discrimination, response choice, and motoric response (Neubauer & Knorr, 1997). It was reported that the process of response choice was the element that was mainly responsible for the significant association between higher intelligence and faster RT. Differences in the drift rate, which represents speed of information processing in the diffusion model of RT performance (Ratcliff, 1978; Ratcliff et al., 2008), have been found to be significantly associated with differences in intelligence (Ravenzwaaij, Brown, & Wagenmakers, 2011).

Working memory capacity has been conceptualized to reflect the ability to control attention and actively maintain necessary information in a temporary store, in the context of interference (Conway, Kane, Engle, 2003; Engle, 2002; Kane & Engle, 2002). Low working memory capacity may lead to lapses in attention and greater susceptibility to distraction during completion of CRT tasks (Schmiedek, Oberauer, Wilhelm, Sub, & Wittmann, 2007). In a study utilizing ex-Gaussian distribution analyses of CRT performance found that the tau parameter, which characterizes longer RTs in the tail of the distribution, as a strong predictor of working memory (Schmiedek et al., 2007). As mentioned in the extended literature review, a higher tau parameter has been conceptualized to indicate lapses in proactive control (Fassbender et al., 2014). Working memory has also been significantly correlated with the
drift rate parameter in the DDM (Schmiedek et al., 2007). Taking this into consideration, a limitation in the current study is that the recruited control group was not matched for education, working memory performance or premorbid intelligence, thus the potential effects of these factors were not controlled for.

Another potential limitation in the current study is the disproportionate gender recruitment, with seventeen males and two females. There is some evidence that gender differences exist when it comes to performance on CRT tasks and this may have influenced the current results given that the sample consisted of predominantly males. Males have been found to perform significantly faster than females on CRT tasks involving speeded decision-making (Adam, 1999; Blough & Slavin, 1987; Prinzel & Freeman, 1995). One study comprised of an investigation into gender differences in a number of tasks, including a CRT task, using a community survey of 7485 people (Jorm, Anstey, Christensen, & Rodgers, 2004). Males were found to perform significantly faster on simple RT and CRT compared with females, however once mediating factors such as levels of education, non-English speaking background, depressive symptoms and physical health, were controlled for, the male advantage disappeared.

The type of response strategies used by males and females have also been examined. Welsh and Elliot (2001) used a dichotic listening task and found that compared with males in their study, women were found to be more likely to use a strategy in which they were attempting to trade RT speed for accuracy. Similarly, Blough and Slavin, (1987) investigated whether males and females performed differently on CRT tasks involving visual-spatial abilities, particularly given the consistent finding that males tend to outperform females on mental rotation and spatial ability tasks (e.g. Halpern, 1992). Blough and Slavin (1987) found that women had significantly longer RTs on CRT tasks that required mental rotation (E.g. inverted shapes), but also in making decisions based on simple forms (e.g. making choices between squares and triangles). However, women also performed significantly more
accurately than males, prompting the authors to suggest that they may have adopted a speed-accuracy trade-off strategy. Prinzel and Freeman (1995) also found that females in their study were more likely than males to adopt a speed-accuracy trade-off strategy when mental rotation requirements increased from 90 degrees to 180 degrees. Prinzel and Freeman (1995) reported that their female sample employed a cautious response style by increasing their RT to maintain their levels of accuracy as task complexity increased. In contrast, male participants were found to maintain the same RT despite increases in task difficulty. Although the Sz and control groups in the present study had equal ratios of gender, it would be curious to see how the threshold parameter would be influenced if a more balanced gender recruitment was to be attained, given that female participants have been found to adopt greater response caution.

3.4 Future directions and recommendations

The results and limitations in the present study prompt a consideration of recommendations for future research. It would be advantageous to recruit a larger sample for added power in the analyses, given that a number of present findings were at trend levels of significance. Future research should aim to recruit a control sample that is better matched for education, premorbid intelligence and working memory, in order to control for the effects of these elements. Better matching of groups on measures of socioeconomic status and parental education would be beneficial in future study, given that lower measures of both have been associated with greater impairments in cognitive functioning (Hackman & Farah, 2009; Kaplan et al., 2001; Turrell et al., 2002). Thus, it is important to dissociate the influence of developmental socioeconomic status and parental education on cognition from the effects of the Sz illness. Better equality in gender during the recruitment process may also help to control for any potential gender effects that may be occurring. It may also be of benefit to assess for the presence of comorbidities such as depression, given the aforementioned
research regarding depressed individuals utilizing different response strategies to non-depressed participants (e.g. Kalb et al., 2006).

As discussed earlier, the present study had originally aimed to also investigate response inhibition in Sz with the use of a stop-signal task. Participants in the present study completed both the go and stop-signal tasks, but unfortunately, due to the time constraints in the current project, the modelling analysis for the stop-signal data was not completed in time and thus only the data from the first testing session was published in the research manuscript. In regards to the LBA model, response inhibition may be explored further by having an additional accumulator representing the stopping process in the stop-signal task, so that successful inhibition occurs if the stop process accumulator reaches its threshold before other choice accumulators. Using a modelling approach to investigate response inhibition may yield further insights into the inhibition deficits in Sz.

Trigger failure refers to the inhibitory process failing to start altogether, which may be due to the stop-signal not being detected or not being encoded properly (Band et al., 2003). It has been suggested that even occasional trigger failures could significantly influence various measures of inhibition, and can lead to a considerable overestimation of SSRT (Band et al., 2003). Trigger failure has not been explored in detail in previous literature; although attempts have been made to investigate it with the use of ZRFT corrected inhibition functions, this method has been found to be unreliable (Band et al., 2003). The stop-signal task in the present experiment was set up in a way as to facilitate investigation intro trigger failure by setting very short SSDs (50ms) on some trials throughout the stop-signal task (please see extended method section in Appendix C). Typically, if a stop-signal is presented very closely to the moment of the stimulus presentation, and the inhibition process is triggered, then response inhibition is highly likely (Verbruggen & Logan, 2009) and the probability of failing to inhibit at these SSDs can be representative of trigger failure. Once again, due to time limitations in the project, the data from stop-signal session were not analysed. Future
research in this area would benefit from a closer examination of the performance on the trials with the very short SSDs in order to better understand differences in trigger failure.

3.5. Clinical implications

The results found in the present paper may provide additional evidence in regards to the cognitive deficits in Sz, namely performance on CRT paradigms. Given the extensive effects that cognitive deficits have on the quality of life and functional outcomes of individuals with Sz (e.g. Green, 1996), gaining further insights into these deficits can help guide the development of targeted interventions, such as cognitive remediation programs. Joyce and Huddy (2004) have argued for the importance of determining specificity in the impairments in Sz and highlight that many studies use neuropsychological tests to evaluate cognition that require several complex and overlapping cognitive processes. They advocate for experimental designs to assess the very basic psychological processes in Sz and carry out investigations beyond examining accuracy and RT’s. This recommendation is congruent with model-based analyses that are able to provide a complete characterization of choice behaviour, as well as model parameter effects being able to provide specific causes for deficits in fast decision-making.

In aging literature, applications of the LBA revealed that slowing in older populations was not actually due to slower evidence accumulation, but in fact due to a higher threshold setting, and that older individuals employed a higher degree of caution in their responding (e.g., Forstmann et al., 2011). It would be advantageous to carry out further similar investigations into the response performance of individuals with Sz, as presently majority of the research focuses on comparisons of mean accuracy and RT scores, and the underlying variables may be missed.
3.6. Conclusion

In conclusion, the present study investigated the underlying components that may be able to explain the patterns of decision-making performance in individuals with Sz. A meta-analysis was conducted and results indicated a consistent pattern of controls having faster and more accurate performance on CRT tasks relative to Sz groups. In traditional analyses of speed and accuracy, individuals with Sz were slower and less accurate relative to controls but this difference was not significant, which was an incongruent finding with previously discussed literature. Model-based analyses revealed more significant findings regarding the threshold and rate parameters in each group, indicating that participants with Sz were more biased to and were more likely to repeat the immediately past response. This finding was discussed in regards to consistent findings of perseveration in Sz across various paradigms relative to controls. The Sz participants also had higher thresholds than control groups, and this result taken together with rate differences was speculated to indicate an attempt at compensating for slow and error prone performance, by increasing the amount of evidence that is required to make a decision. This was discussed in light of literature regarding the flexibility of responding in Sz and potential attempts at speed-accuracy trade-offs.

This study also demonstrated the utility of model-based analyses that were found to provide greater insights into the underlying variables of speeded decision-making performance than traditional analyses alone. Findings regarding the threshold and rate parameters would have been obscured if modelling analyses were not carried out, and such findings would be worth replicating and extending upon in future research. Furthermore, the potential implications of impaired motion perception deficits as well as the influence of anti-psychotic and anti-depressant medication were proposed. Future research in this area would benefit from closer control group matching in terms of variables assessed, such as premorbid intelligence, working memory, and levels of education, as the group differences in these
variables may confound results. A more balanced recruitment of gender may be warranted in future studies given the differential response strategies that have been reportedly used by males and female.

Finally, the investigations carried out in the present experiment may be extended in future research to examine response inhibition deficits in Sz and potential occurrences of trigger failure. Further investigations into trigger failure are necessary given the potential effect it may have on estimations of response inhibition performance in stop-signal paradigms.

In conclusion, while more work needs to be conducted in this area in order to extend and replicate these findings, the present study was able to provide novel insights into the performance of individuals with Sz on a task that requires fast decision-making. Given the pervasive nature of cognitive impairments in Sz, it is important to continue the investigation into the underlying causes and processes of such deficits in order to develop targeted interventions and gain a better understanding of the daily struggles experienced by those affected by Sz.
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Appendix A. Diffusion Drift Model Parameter Analysis

DDM Parameter Analysis

We first analysed the parameter estimates from the top DDM model. Most of the significant effects were on mean drift rate. There was a strong main effect of difficulty, $F(1,36) = 15.4, p < .001$, due to a greater rate for easy (0.22) than hard (0.13) stimuli. This effect is to be expected, with the larger rate leading to more accurate and faster responding for easy stimuli. There was also a significant interaction between difficulty, stimulus and group, $F(1,36) = 6.7, p = .014$. The interaction was due to the difficulty effect (i.e., easy – hard) being larger for right than left stimuli (0.14 vs. 0.11) in controls but smaller for right than left stimuli (0.05 vs. 0.07) in patients. This rather complex interaction effect is difficult to interpret.

Consistent with AIC model selection, there was a significant main effect of last response on the starting point parameter, $F(1,36) = 4.43, p = .042$. The main effect indicated a slight bias towards the right response ($z/a = .518$) when the last response was left and almost unbiased responding when the last response was right ($z/a = .504$). Again the interpretation of this finding is unclear, as it is inconsistent with the general tendency towards repetition rather than alternation. No other effects of last response were significant.

A greater rate for controls than patients (0.23 vs. 0.12) almost achieved significance, $F(1,36) = 3.98, p = .054$. When considering only drift rates for 10% coherence conditions the numerical difference was the same but statistically weaker, $F(1,36) = 2.3, p = .14$. Although neither effect is significant, the directions of the trends are at least interpretable in terms of slower and less accurate performance for patients than controls.

It is possible that these mostly weak and difficult to interpret effects are due to overfitting in the top model. In the AIC model, where all repeated measures effects were on mean
rates the group difference (0.2 vs. 0.1) achieved significance, F(1,36) = 5.3, \( p = .027 \). The group effect when considering only 10\% coherence conditions was also enhanced, becoming marginally significant, F(1,36) = 3.1, \( p = .09 \). The main effect of difficulty, F(1,36) = 16.4, \( p < .001 \), and its interaction with group and stimulus, F(1,36) = 6.1, \( p = .018 \), continued to be significant in the AIC selected model, and had the same pattern of effect.
Appendix B. Analysis of covariate effects

We also examined correlations with WTAR and LNS scores for all participants and positive, negative and disorganization scores in patients. For accuracy and RT measures we focused on the 10% coherence condition to avoid confounds from differences in easy vs. hard pair assignment. There was a significant positive correlation between accuracy and WTAR, $r = .49$, $t(34) = 2.45$, $p = .02$. No other correlations with WTAR or LNS were significant ($p > .5$ in all cases).

For patients, there was a significant positive correlation between mean correct RT and negative symptoms, $r = .45$, $t(17) = 2.4$, $p = .03$, and a marginal correlation with correct RT standard deviation, $r = .4$, $t(17) = 1.8$, $p = .09$. The only other correlations to approach significance (otherwise $p > .2$) were between positive symptoms and mean correct RT, $r = .38$, $t(17) = 1.7$, $p = .1$, and correct RT standard deviation, $r = .32$, $t(17) = 1.4$, $p = .18$.

For patients, neither the autocorrelations nor their squares correlated significantly with any of the three symptom measures ($p > .4$ in all cases). In the overall sample there was only one marginally significant correlation between LNS or WTAR scores and either autocorrelations or squared autocorrelations, a negative correlation between LNS and squared autocorrelation, $r = -0.31$, $t(34) = 1.89$, $p = .07$. This correlation did not appear to be group specific as was weakened when calculated separately in each group.
Appendix C. Extended description of method

1. Method

1.1 Ethics

Approval to conduct the study was obtained from the Hunter New England Health Human Research Ethics Committee and the Human Research Ethics Committee at The University of Newcastle. Informed consent was obtained from all participants prior to the commencement of the study.

1.2 Participants

A total of twenty-six participants with schizophrenia or schizoaffective disorder who were recruited from a clozapine clinic held at the Newcastle Community Mental Health Service. Clozapine is an atypical anti-psychotic that often requires close monitoring such as regular health check-ups and blood tests. The participant’s treating clinician or case manager was firstly approached to confirm the participant’s diagnosis, their ability to provide informed consent, and whether the study would be suitable for them. Seven clinical participants were excluded from further analyses due to low accuracy (close to 50% accuracy) in their performance on either the go or stop-signal task, so the Sz group consisted of a total of sixteen males and three females (n = 19) with a diagnosis of schizophrenia (n = 17) or schizoaffective disorder (n = 2). Participants were excluded from participating in the study if they had a history of neurological trauma, a diagnosis of intellectual disability, or current drug or alcohol dependence. Table 1 provides a summary of medication taken by the participants at the time of testing. One participant reported undergoing a series of maintenance electroconvulsive therapy (ECT) treatments in the six months prior to participating in the research study. Sz participants were provided with monetary reimbursement to cover the costs associated with participants in the research.
Nineteen healthy control participants were recruited and matched with the clinical participants by age and gender. Participants were recruited from the University of Newcastle (n = 4) from a student pool register consisting of students enrolled in a first-year Psychology course and were awarded course credit for their participation. Other healthy controls were recruited from a register of healthy volunteers at the Hunter Medical Research Institute (n = 6) and from the local community (n = 9), and received monetary reimbursement to cover the costs associated with participation. Healthy controls were excluded from participating in the research study if they met the aforementioned exclusion criteria or if they had a diagnosis of a mental illness.

The two groups did not differ in age (Sz mean age = 37.6 years, SD = 6.24; controls mean age = 38.8 years, SD = 8.96), but did differ significantly in their education level (Table 1).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Schizophrenia (n = 19)</th>
<th>Controls (n = 19)</th>
<th>Parametric test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD)</td>
<td>t values</td>
</tr>
<tr>
<td>Age (years)</td>
<td>37.6 (6.5)</td>
<td>38.8 (9)</td>
<td>-0.47</td>
</tr>
<tr>
<td>Education*</td>
<td>2.8 (1.4)</td>
<td>5 (0.8)</td>
<td>-6.08</td>
</tr>
<tr>
<td>WTAR scaled score</td>
<td>94 (15.4)</td>
<td>109.4 (24.7)</td>
<td>-2.33</td>
</tr>
<tr>
<td>LNS scaled score</td>
<td>8.05 (2.5)</td>
<td>11.5 (3.7)</td>
<td>-3.36</td>
</tr>
<tr>
<td>SAPS</td>
<td>3.4 (3.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SANS</td>
<td>10.2 (3.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disorganization symptoms</td>
<td>2.4 (2.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Days between go and stop-task sessions</td>
<td>8.8 (3.1)</td>
<td>9.4 (6.5)</td>
<td>-0.383</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gender</th>
<th>n (%)</th>
<th>n (%)</th>
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</thead>
<tbody>
<tr>
<td>Male</td>
<td>16 (84.2)</td>
<td>16 (84.2)</td>
</tr>
<tr>
<td>Female</td>
<td>3 (15.8)</td>
<td>3 (15.8)</td>
</tr>
<tr>
<td>Diagnosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schizophrenia</td>
<td>17 (89.5)</td>
<td></td>
</tr>
<tr>
<td>Schizoaffective disorder</td>
<td>2 (10.5)</td>
<td></td>
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</tbody>
</table>
Medication type

<table>
<thead>
<tr>
<th>Type</th>
<th>Count (Percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clozapine</td>
<td>18 (94.7)</td>
</tr>
<tr>
<td>Other atypical antipsychotics</td>
<td>10 (52.6)</td>
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<tr>
<td>Typical antipsychotics</td>
<td>1 (5.3)</td>
</tr>
<tr>
<td>Antidepressants</td>
<td>7 (36.8)</td>
</tr>
<tr>
<td>Lithium carbonate</td>
<td>1 (5.3)</td>
</tr>
<tr>
<td>Anticonvulsants</td>
<td>3 (15.8)</td>
</tr>
</tbody>
</table>

* Education codes:
0 = below Year 10
1 = Year 10/4th form (school certificate/equivalent)
2 = Year 11/5th form (leaving certificate/equivalent)
3 = Year 12/6th form (HSC/equivalent)
4 = Technical College or TAFE College
5 = Graduate (Bachelor degree)
6 = Post-graduate (Masters degree/PhD)

1.3 Go and stop-signal tasks

Apparatus and stimuli

The stimuli for the go and stop-signal tasks comprised of a random dot kinematogram (RDK) stimulus, which was presented on a personal computer in a quiet room. This RDK consisted of 40 dots within an invisible circular border area 50mm in diameter. The dots moved randomly, being redrawn at the rate of 30 frames per second, except for a proportion of dots moved coherently 45 degrees either to the top left or top right direction. The proportion of dots moving coherently in one direction determined the difficulty of the trial, so that the higher the coherence, the easier it was to determine the direction of the dots. Participants were instructed to judge the direction of the movement of the dots by pressing the “Z” key with their left hand or the “/” with their right hand, which were clearly labelled on the computer keyboard.

A fixation point of 250ms preceded each presentation of the RDK stimulus. Initially, the inter-stimulus interval for each trial was fixed at 2000ms, however preliminary data analysis revealed that some participants’ RT distributions were truncated at the 2000ms mark.
As a result, the length of stimulus presentation was extended to a fixed length of 3000ms. The inter-trial interval was 500ms in duration.

*The go task*

The go task comprised of 9 blocks with 49 trials in each block, with the first block being a practice block intended to allow participants to familiarise themselves with the task. In the practice block, the coherence of dots travelling in the same direction started at 65%, and continued to decrease gradually (e.g., 65%, 54%, 48%, and so on) until it reached 20%. The second and third blocks contained three difficult levels, 5%, 10%, and 20% coherence and the average accuracy was determined for the easier pair (10% and 20%) and the harder pair (5% and 10%). Whichever coherence pair had an average accuracy closer to 75% was used as the difficulty level for the remaining blocks. This was done in attempt to reduce potential floor or ceiling effects in accuracy due to individual differences in ability. Between each block, participants were encouraged to take a rest for as long as they required and continue onto the next block by pressing the space bar. This task took approximately 20 minutes to complete.

Participants were encouraged to perform as quickly as they can, but also to try to be accurate in their responding. For correct responses, participants were provided with feedback on their reaction time in milliseconds in order to increase motivation and reinforce rapid responding. Incorrect choices were followed by “incorrect” displayed on the screen and “too slow” if participants failed to respond within 3000ms.

*The stop-signal task*

The stop-signal task consisted of 12 blocks of 49 trials. The same coherency levels from the go task were used in the stop task. Fourteen randomly selected trials per block (approximately 29% of trials), contained a visual stop-signal which was a grey border
appearing around the RDK stimuli. This is close to the optimal stop-signal frequency suggested by Logan (1994) of 25%, and is argued to balance having enough stop-signal trials to make inferences from, with the possibility of participants employing stopping strategies such as slowing go RT in order to increase likelihood of successful inhibition (Fletcher, 2011; Verbruggen & Logan, 2009). This grey border also appeared during the go task in order to familiarise participants with it, but during that task they were instructed to simply ignore it. In the stop-signal task, participants similarly made key-presses to indicate the direction of the RDK stimuli as done on the go task, however they were also instructed to withhold making a response whenever a stop-signal was presented. Participants were instructed to focus on rapid responding and encouraged not to slow their responding in order to inhibit more successfully. This task took approximately forty minutes to complete.

The fixed SSD of 50ms was used for 2 randomly selected trials per block in order to investigate trigger failure. This short SSD makes it extremely difficult for the participant to respond to the go stimuli and increases the chance of successful inhibition. The remaining SSDs were set by the staircase tracking procedure (Levitt, 1971). The first staircase SSD was 200ms, and the following SSDs changed dynamically depending on the participants’ success in inhibiting on the previous stop trial. For instance, if the participant successfully inhibited at a particular SSD, the next SSD was increased by 33ms. On the other hand, if they failed to inhibit, the subsequent SSD was decreased by 33ms. This tracking procedure prevents strategies at being developed to aid inhibition, keeps inhibitory success at approximately 50% (Levitt, 1971), and has been suggested as an optimal method for setting SSDs in order to obtain the most accurate estimates of SSRT (Band et al., 2003). The tracking procedure can help to account for individual differences between subjects by resulting in a similar probability of responding given the occurrence of a stop-signal across various conditions or subjects (Verbruggen & Logan, 2009).
1.4 Other measures

Letter Number Sequencing

Participants completed the Letter-Number Sequence (LNS), which is a subtest of the Wechsler Adult Intelligence Scale, third edition (WAIS-III; Wechsler, 1997) as a measure of working memory (WM). In this test, the participants were orally presented with a series of letters and numbers in a mixed-up order. The participants were required to rearrange these numbers and letters so that the numbers are in chronological order, followed by the letters that are in alphabetical order. WM capacity has been found to influence performance in tasks measuring response inhibition (Colflesh & Conway, 2007; Hester & Garavan, 2005; Kane & Engle, 2003). Given that WM deficits have been widely reported in schizophrenia (Green et al., 2004; Lee & Park, 2005; Quee, Eling, van der Heijden, & Hildebrandt, 2011; Silver, Feldman, Bilker, & Gur, 2003), the LNS was included in the experiment to be analysed as a covariate.

Wechsler Test of Adult Reading

Participants completed The Wechsler Test of Adult Reading (WTAR) (The Psychological Corporation, 2001) which assesses premorbid functioning in adults. In this task, participants were presented with a word card and were required to pronounce 50 irregularly spelled words.

The Scale for the Assessment of Positive and Negative Symptoms

Participants with Sz were administered The Scale for the Assessment of Positive and Negative Symptoms (SAPS/SANS) (Andreasen, 1983; 1984). The SAPS/SANS is a semi-structured clinical interview that assesses the presence of positive, negative symptoms as well as disorganisation symptoms that typically occur in schizophrenia. The interview took
approximately 45 minutes to 1 hour to administer, depending on the extent of the symptoms. The SAPS/SANS has been found to have good inter-rater reliability, modest internal consistency and strong construct validity (Peralta & Cuesta, 1994). In line with the principal components analysis of the SAPS/SANS by Andreasen, Arndt, Alliger, Miller, and Flaum (1995), the items of SAPS were separated so that global scores for hallucinations and delusions were added together to form a total score for positive symptoms, and global scores for bizarre behaviour and positive formal thought disorder were summed to obtain a total score for disorganization symptoms. Similarly, global scores on SANS items, affective flattening, alogia, avolition-apathy and anhedonia-asociality were added to establish a total score for negative symptoms. Scores on the attention subscale of the SAPS/SANS were omitted, as it is not considered to be a core component of negative symptomology (Blanchard & Cohen, 2006).

1.5 Procedure

The complete experiment took place over two separate sessions, typically a week apart and at a minimum 24 hours apart. For the clinical group, the second session took place an average of 8.79 days (SD= 3.08) after the first session, and for the control group, it occurred an average of 9.42 days (SD = 6.49) later (Table 1). In the first session, participants completed a demographic questionnaire, the go-task, the LNS, and the WTAR. In the second session, all participants completed the stop-task and participants with Sz also completed the clinical interview.
Appendix D. Ethics approval

31 August 2012

Professor A Heathcote
School of Psychology
University of Newcastle

Dear Professor Heathcote,

Re: Slowing and stopping in schizophrenia (12/07/18/4.05)

HNEHREC Reference No: 12/07/18/4.06
NSW HREC Reference No: HREC/12/HNE/229

Thank you for submitting the above protocol for single ethical review. This project was first considered by the Hunter New England Human Research Ethics Committee at its meeting held on 18 July 2012. This Human Research Ethics Committee is constituted and operates in accordance with the National Health and Medical Research Council’s National Statement on Ethical Conduct in Human Research (2007) (National Statement) and the CPMP/ICH Note for Guidance on Good Clinical Practice. Further, this Committee has been accredited by the NSW Department of Health as a lead HREC under the model for single ethical and scientific review. The Committee’s Terms of Reference are available from the Hunter New England Local Health District website: http://www.hnehealth.nsw.gov.au/Human_Research_Ethics.

I am pleased to advise that following acceptance under delegated authority of the requested clarifications and revised Information Statement, Consent Form and Advertisements by Dr Nicole Gerrand Manager, Research Ethics & Governance, the Hunter New England Human Research Ethics Committee has granted ethical approval of the above project.

The following documentation has been reviewed and approved by the Hunter New England Human Research Ethics Committee:

- For the Participant Information Sheet (Version 2 dated 30 August 2012);
- For the Control Participant Information Sheet (Version 1 dated 30 August 2012);
- For the Consent Form (Version 2 dated 28 August 2012);
- For the Advertisement Flyer;
- For the Wechsler Adult Test of Reading (WTAR); and
- For the Clinical Interview – Scale for the Assessment of Positive and Negative Symptoms (SAPS/SANS)

For the protocol: Slowing and stopping in schizophrenia

Approval has been granted for this study to take place at the following site:

Hunter New England Local Health District

Hunter New England Research Ethics & Governance Unit

Locked Bag No 1
New Lambton NSW 2305
Telephone (02) 49214 950 Facsimile (02) 49214 816
Email: hnehrec@hnehealth.nsw.gov.au

Approval from the Hunter New England Human Research Ethics Committee for the above protocol is given for a maximum of 3 years from the date of this letter, after which a renewal application will be required if the protocol has not been completed.

The National Statement on Ethical Conduct in Human Research (2007), which the Committee is obliged to adhere to, include the requirement that the committee monitors the research protocols it has approved. In order for the Committee to fulfill this function, it requires:

- A report of the progress of the above protocol be submitted at 12 monthly intervals. Your review date is August 2013. A proforma for the annual report will be sent two weeks prior to the due date.

- A final report must be submitted at the completion of the above protocol, that is, after data analysis has been completed and a final report compiled. A proforma for the final report will be sent two weeks prior to the due date.

- All variations or amendments to this protocol, including amendments to the Information Sheet and Consent Form, must be forwarded to and approved by the Hunter New England Human Research Ethics Committee prior to their implementation.

- The Principal Investigator will immediately report anything which might warrant review of ethical approval of the project in the specified format, including:
  - any serious or unexpected adverse events
    - Adverse events, however minor, must be recorded as observed by the investigator or as volunteered by a participant in this protocol. Full details will be documented, whether or not the investigator or his deputies considers the event to be related to the trial substance or procedure. These do not need to be reported to the Hunter New England Human Research Ethics Committee.
    - Serious adverse events that occur during the study or within six months of completion of the trial at your site should be reported to the Manager, Research Ethics & Governance, of the Hunter New England Human Research Ethics Committee as soon as possible and at the latest within 72 hours.
    - Serious adverse events are defined as:
      - Causing death, life threatening or serious disability.
      - Cause or prolong hospitalisation.
      - Overdoses, cancers, congenital abnormalities whether judged to be caused by the investigational agent or new procedure or not.
      - Unforeseen events that might affect continued ethical acceptability of the project.

Hunter New England Research Ethics & Governance Unit
Locked Bag No 1
(New Lambton NSW 2305)
Telephone (02) 49214 810 Facsimile (02) 49214 818
Email: hnehrec@hnehealth.nsw.gov.au
• If for some reason the above protocol does not commence (for example it does not receive funding); is suspended or discontinued, please inform Dr Nicole Gerrand, as soon as possible.

You are reminded that this letter constitutes ethical approval only. You must not commence this research project at a site until separate authorisation from the Chief Executive or delegate of that site has been obtained.

A copy of this letter must be forwarded to all site investigators for submission to the relevant Research Governance Officer.

Should you have any concerns or questions about your research, please contact Dr Gerrand as per the details at the bottom of the page. The Hunter New England Human Research Ethics Committee wishes you every success in your research.

Please quote 12/07/18/4.05 in all correspondence.

The Hunter New England Human Research Ethics Committee wishes you every success in your research.

Yours faithfully

Professor M Parsons
Chair
Hunter New England Human Research Ethics Committee
Appendix E. Information and consent forms for clinical participants

Consent Form for the Research Project:

“Slowing and stopping in schizophrenia”

Investigators: Prof Andrew Heathcote (Chief Investigator)
               Emeritus Professor Pat Michie (Associate Investigator)
               Mr Jonathon Love (Associate Investigator)
               Ms Anna Suraev (Student Researcher)
               Ms Charlene Gong (Student Researcher)
               Mr Sam Curley (Student Researcher)

Consent Form

- I agree to participate in the project ‘Slowing and stopping in schizophrenia’ and give my consent freely.

- I understand that the project will be conducted as described in the Participant Information Sheet a copy of which I have retained.

- I understand that I can withdraw from the project at any time and do not have to give any reasons for withdrawing.

- I realise that whether or not I decide to participate my decision will not affect my further medical treatment.

- I agree for the researcher to pass on any relevant information obtained during my participation in the project to my treating clinician.

- I have had all questions answered to my satisfaction.

Print Name ____________________________ Signature ____________________________ Date __________

Investigator: Prof Andrew Heathcote
Consent Form
Version 4 dated 21/03/2013

1
Participant Information Sheet

Slowing and Stopping in Schizophrenia

You are being invited to take part in a research study. The study is being undertaken by Professor Andrew Heathcote (Chief Investigator & research supervisor), Emeritus Professor Pat Michie (Associate Investigator), Jonathon Love (Associate Investigator), Anna Suraev (Student Researcher), Charlene Gong (Student Researcher) and Sam Curley (Student Researcher) at the School of Psychology University of Newcastle.

Before you decide whether or not you wish to take part, it is important for you to know why the research is being done and what it involves. Please take time to read the following information carefully and discuss it if you wish with relatives, friends and your family doctor (GP). Take your time to decide whether or not you wish to take part.

If you decide to participate, you will be given a hard copy of this form to keep for your records.

Why is the research being done?
The purpose of this study is to investigate how individuals with schizophrenia or schizo-affective disorder perform on a task that measures their ability to stop or inhibit a planned response or behaviour. In particular, we would like to better understand how individuals with a diagnosis of schizophrenia or schizo-affective disorder perform on this type of task compared to those individuals who do not have these diagnoses.

Also, we would like to assess the value of a new method of analysing a person’s ability to stop a planned response or behaviour on this computer task. Finally, we would like to get a better understanding of the relationship between a person’s ability to stop a planned response or behaviour and the severity of their symptoms of schizophrenia or schizo-affective disorder.

Who can participate in the research?
If you are a person aged between 18 and 65 and you have a diagnosis of schizophrenia or schizo-affective disorder, then this study may be suitable for you. We are also recruiting individuals who do not have a diagnosis of schizophrenia or schizo-affective disorder to participate in the current study.
This study would not be suitable for you, if you have had any of the following conditions: a previous severe traumatic brain injury associated with a loss of consciousness, diagnosis with intellectual disability, or having a drug or alcohol dependence within the last twelve months.

**What does giving consent mean?**
Giving consent means that you are able to make a decision about your participation in a research project based on being provided with clear information of what is involved in the research, and the likely benefits and risks. Part of this process you will also have the opportunity to take this information away with you and have time to think about it and discuss it with your doctor of friends and family. You will also be provided with the opportunity to ask the researchers any questions about the research project and to clarify anything you may not be sure about. Your decision to participate is entirely voluntary and whether you decide to participate or not will not affect your current or future care.

**What choice do you have?**
Participation in this research study is completely voluntary. You may refuse to take part in the study or you may stop your participation in the study at any time without giving a reason. Your decision will not disadvantage you in any way and will not affect your current or future care. If you decide to withdraw from the study, you can choose for all the data about you to be securely destroyed. Only those people who give their informed consent will be included in the project.

**What does the study involve?**
After reviewing the details of the study, you will be asked to sign a consent form if you wish to participate. We will contact you via telephone and arrange a time for you to attend two testing sessions on separate days.

**Computer task (40 mins):** On the first testing session, we will ask you to participate in a simple computer task, which takes approximately 40 minutes to complete. In this computer task you are required to watch a series of dots on a computer screen moving in different directions, and make a decision about which direction you think they might be moving (e.g. left or right). You will be required to make this decision by pressing a specific key on a computer keyboard. There will be a number of opportunities to take regular breaks throughout this task. On the second testing session, you will complete exactly the same computer task describe above, but this time whenever you see a grey border appear around the dots, you will withhold making a key-press on the keyboard. This task will be explained to you before you start and you will have an opportunity to ask questions.

**Working memory task (5 mins):** You will hear numbers and letters read out loud to you and you will be asked to recall what you heard but place the numbers in order of lowest to highest and the letters in alphabetical order. This task will be explained to you in detail before you start.

**Reading words task (5 mins):** You will be asked to read a short list of words and your responses will be recorded on paper.
Clinical interview (1 hour - 1.5 hours): You will do a one-on-one interview with the researcher where you will discuss some of the symptoms of schizophrenia or schizoaffective disorder that you experience. This interview will take approximately 1-1.5 hours to complete and you may choose on which testing session you would like to complete it.

How much time will it take?
You will be asked to attend two testing sessions on different days approximately one week apart.

Session 1: you will complete the two computer tasks, the reading words task and an interview = total 2–2.5 hours
Session 2: you will complete a computer task = total 40 minutes

So in total, your participation in this study will take approximately 3 hours – 3.5 hours and this includes short breaks and time for tasks to be explained. You may also choose to do the interview in the second session if you wish.

What are the risks and benefits of participating?
You may not benefit directly from participating in this study. We do not anticipate any specific risks associated with participating in this study. While most people with schizophrenia find it helpful to discuss their experiences, a person can, on occasion, become distressed. If this starts to happen to you please tell the interviewer. If after the interview, you are still feeling distressed or feel that there are issues that you would like to discuss further, we advise that you contact your treating clinician or case manager. Alternatively, we can arrange for an independent counselling service to be provided at no cost to you. You may also wish to contact Lifeline on 13 11 14 whilst awaiting the appointment with the counsellor.

How will your privacy be protected?
We will keep this information private. Data collected for study will be stored within a locked filing cabinet at the School of Psychology at the University of Newcastle where it will only be accessible to the researchers in the project. Data will be accessed, used and stored in accordance with Commonwealth Privacy Laws and the NSW Health Records and Information Privacy Act 2002.

How will the information be collected and used?
Information will be collected by you making specific key presses on a computer keyboard in response to what you see on the screen. We will also collect some demographic information about you in the interview as well as some information about your experiences of your symptoms of schizophrenia. The information we collect will be used for papers in scientific journals. Individual participants will not be identified in any way. We will also ask you for permission for us to forward any relevant results from the research study to your treating clinician.

What do you need to do to participate?
Please read this information sheet and be sure you understand its contents before you consent to participate. If there is anything you do not understand, or you have questions, contact the researcher. If you would like to participate then please read and sign the consent form.

Thank you for considering this invitation,

Professor Andrew Heathcote  
Emeritus Professor Pat Michie  
School of Psychology  
School of Psychology  
University of Newcastle  
University of Newcastle

Ms Anna Suraev  
Mr Jonathon Love  
Professional Doctorate in Clinical psychology Candidate  
Bachelor of Psychology (Honours)  
University of Newcastle  
University of Newcastle

Ms Charlene Gong  
Mr Sam Curley  
Bachelor of Psychology (Honours)  
Bachelor of Psychology (Honours)  
Candidate  
Candidate  
University of Newcastle  
University of Newcastle

Complaints
This research has been reviewed and approved by the Hunter New England Area Research Ethics Committee of Hunter New England Health, Reference No 12/07/18/4/05

Should you have any concerns about your rights as a participant in this research, or you have a complaint about the manner in which the research is conducted, it may be given to the researcher, or, if an independent person is preferred, to Dr Nicole Gerrand, Manager Research Ethics and Governance, Hunter New England Health, Hunter New England Health, Locked Bag 1, New Lambton NSW 2305, telephone (02) 4921 4950, email HNEHREC@hnehealth.nsw.gov.au
Appendix F. Information and consent forms for control participants

Consent Form for the Research Project:
‘Slowing and stopping in schizophrenia’

Investigators: Prof Andrew Heathcote (Chief Investigator)
Emeritus Professor Pat Michie (Associate Investigator)
Mr Jonathon Love (Associate Investigator)
Ms Anna Suraev (Student Researcher)
Ms Charlene Gong (Student Researcher)
Mr Sam Curley (Student Researcher)

Consent Form

• I agree to participate in the project ‘Slowing and stopping in schizophrenia’ and give my consent freely.

• I understand that the project will be conducted as described in the Participant Information Sheet a copy of which I have retained.

• I understand that I can withdraw from the project at any time and do not have to give any reasons for withdrawing. All the information obtained during this research will be kept strictly confidential.

• I have had all questions answered to my satisfaction.

____________________ _________________ ___________
Print Name Signature Date
Participant Information Sheet

Slowing and Stopping in Schizophrenia

You are being invited to take part in a research study. The study is being undertaken by Professor Andrew Heathcote (Chief Investigator & student research supervisor), Emeritus Professor Pat Michie (Associate Investigator), Jonathon Love (Associate Investigator), Anna Suraev (Student Researcher) Charlene Gong (Student Researcher) and Sam Curley (Student Researcher) at the School of Psychology, the University of Newcastle.

Before you decide whether or not you wish to take part, it is important for you to know why the research is being done and what it involves. Please take time to read the following information carefully and discuss it if you wish with relatives, friends and your family doctor (GP). Take your time to decide whether or not you wish to take part. If you decide to participate, you will be given a hard copy of this form to keep for your records.

Why is the research being done?
The purpose of this study is to investigate how individuals with schizophrenia or schizo-affective disorder perform on a task that measures their ability to stop or inhibit a planned response or behaviour. In particular, we would like to better understand how individuals with a diagnosis of schizophrenia or schizo-affective disorder perform on this type of task compared to those individuals who do not have these diagnoses.

Also, we would like to assess the value of a new method of analysing a person’s ability to stop a planned response or behaviour on this computer task. Finally, we would like to get a better understanding of the relationship between a person’s ability to stop a planned response or behaviour and the severity of their symptoms of schizophrenia or schizo-affective disorder.

Who can participate in the research?
If you are a person aged between 18 and 65 and you do not have a diagnosis of schizophrenia or schizo-affective disorder then this study may be suitable for you.

This study would not be suitable for you, if you have had any of the following conditions: a previous severe traumatic brain injury associated with a loss of consciousness, diagnosis with intellectual disability, or having a drug or alcohol dependence within the last twelve months.
What does giving consent mean?
Giving consent means that you are able to make a decision about your participation in a research project based on being provided with clear information of what is involved in the research, and the likely benefits and risks. Part of this process you will also have the opportunity to take this information away with you and have time to think about it and discuss it with your doctor of friends and family. You will also be provided with the opportunity to ask the researchers any questions about the research project and to clarify anything you may not be sure about. Your decision to participate is entirely voluntary and whether you decide to participate or not will not affect your current or future care.

What choice do you have?
Participation in this research study is completely voluntary. You may refuse to take part in the study or you may stop your participation in the study at any time without giving a reason. Your decision will not disadvantage you in any way and will not affect your current or future care. If you decide to withdraw from the study, you can choose for all the data about you to be securely destroyed. Only those people who give their informed consent will be included in the project.

What does the study involve?
After reviewing the details of the study, you will be asked to sign a consent form if you wish to participate. We will contact you via telephone and arrange a time for you to attend two testing sessions on separate days.

Computer task: On the first testing session, we will ask you to participate in a simple computer task, which takes approximately 40 minutes to complete. In this computer task you are required to watch a series of dots on a computer screen moving in different directions, and make a decision about which direction you think they might be moving (e.g. left or right). You will be required to make this decision by pressing a specific key on a computer keyboard. There will be a number of opportunities to take regular breaks throughout this task. On the second testing session, you will complete exactly the same computer task describe above, but this time whenever you see a grey border appear around the dots, you will withhold making a key-press on the keyboard. This task will be explained to you before you start and you will have an opportunity to ask questions.

Working memory task 1 (15): You will be asked to do another task on the computer that will measure your ability of holding information in your mind over a short period of time. This task involves judging whether simple mathematical equations are correct or incorrect and also remembering some of the letters that will be presented to you on the screen. This task will also be explained in detail before you start.

Working memory task 2 (5 mins): You will hear numbers and letters read out loud to you and you will be asked to recall what you heard but placing the numbers in order of lowest to highest and the letters in alphabetical order. This task will be explained to you in detail before you start.

Reading words task (5 mins):
You will be asked to read a short list of words and your responses will be recorded on paper.
Video Games Questionnaire (5 mins):
You will be asked a few brief questions about how often you play video games and will make a response by selecting a number on a scale ranging from 1 = Never and 5 = Very often. Also, the researcher will ask you a few basic demographic questions (e.g. age, education, etc).

How much time will it take?
You will be asked to attend two testing sessions on different days approximately one week apart.

Session 1: you will complete a computer task, two working memory tasks, video games questionnaire and the reading works task = total approximately 1 hour 5 mins

Session 2: you will complete a computer task = total 40 minutes

So in total, your participation in this study will take approximately 1 hour 45 min - 2 hours and this includes short breaks and time for tasks to be explained.

What are the risks and benefits of participating?
You may not benefit directly from participating in this study. We do not anticipate any specific risks associated with participating in this study.

How will your privacy be protected?
We will keep this information private. Data collected for study will be stored within a locked filing cabinet at the School of Psychology at the University of Newcastle where it will only be accessible to the researchers in the project. Data will be accessed, used and stored in accordance with Commonwealth Privacy Laws ad the NSW Health Records and Information Privacy Act 2002.

How will the information be collected and used?
Information will be collected by you making specific key presses on a computer keyboard in response to what you see on the screen and this data will be recorded on a computer. We will also collect some demographic information about you. The information we collect will be used for papers in scientific journals. Individual participants will not be identified in any way.

What do you need to do to participate?
Please read this information sheet and be sure you understand its contents before you consent to participate. If there is anything you do not understand, or you have questions, contact the researcher. If you would like to participate then please read and sign the consent form.

Thank you for considering this invitation,

Professor Andrew Heathcote          Emeritus Professor Pat Michie
School of Psychology                  School of Psychology
University of Newcastle              University of Newcastle
Ms Anna Suraev
Professional Doctorate in Clinical Psychology Candidate
University of Newcastle

Mr Jonathon Love
Bachelor of Psychology (Honours)
University of Newcastle

Ms Charlene Gong
Bachelor of Psychology (Honours) Candidate
University of Newcastle

Mr Sam Curley
Bachelor of Psychology (Honours) Candidate
University of Newcastle

Complaints
This research has been reviewed and approved by the Hunter New England Area Research Ethics Committee of Hunter New England Health, Reference No 12/07/18/4/05

Should you have any concerns about your rights as a participant in this research, or you have a complaint about the manner in which the research is conducted, it may be given to the researcher, or, if an independent person is preferred, to Dr Nicole Gerrand, Manager Research Ethics and Governance, Hunter New England Health, Hunter New England Health, Locked Bag 1, New Lambton NSW 2305, telephone (02) 4921 4950, email HNEHREC@hnehealth.nsw.gov.au
Appendix G. Demographics Questionnaire

Brief Demographics Survey

1. I am a male/female

2. I am _________ years old (please specify to month, e.g., 34 years 2 months).

3. Please circle the highest level of education you have completed:

   Never attended school                      Year 7 (1st form)                      Year 12 (6th form, HSC or equivalent)
   Year 1 (grade 1)                             Year 8 (2nd form)                           
   Year 2 (Grade 2)                             Year 9 (3rd form, intermediate certificate or equivalent)
   Year 3 (Grade 3)                             Technical college or TAFE College
   Year 4 (Grade 4)                             Year 9 (3rd form, intermediate certificate or equivalent)
   Year 5 (Grade 5)                             Undergraduate (Bachelor degree, etc)
   Year 6 (Grade 6)                             Postgraduate (Masters, PhD, etc)
   Year 11 (5th form, leaving certificate or equivalent)

4. I have been diagnosed with mental illness: No/ Yes
   If you answered Yes, please specify ____________________________

We can provide individuals from Aboriginal or Torres Strait Islander origin with access to an Aboriginal Liaison Officer who can provide support on your decision to participate in the research.
Appendix H: Notes for contributors to the Journal of Abnormal Psychology

Submission

Submit manuscripts electronically (in .rtf or .doc format) via the Manuscript Submission Portal.

Sherryl H. Goodman, PhD
Editor, Journal of Abnormal Psychology
Department of Psychology
Emory University
36 Eagle Row
Atlanta, GA 30322

General correspondence may be directed to the Editor's Office.

Masked Reviews

Masked reviews are optional and must be specifically requested in the cover letter accompanying the submission. For masked reviews, the manuscript must include a separate title page with the authors' names and affiliations, and these ought not to appear anywhere else in the manuscript.

Footnotes that identify the authors must be typed on a separate page.

Make every effort to see that the manuscript itself contains no clues to authors’ identities.

Types of Articles

Most of the articles published in the Journal of Abnormal Psychology® are reports of original research, but other types of articles are acceptable.

- Short Reports of replications or of failures to replicate previously reported results are given serious consideration.
- Comments on articles published in the journal are also considered.
- Case Studies from either a clinical setting or a laboratory will be considered if they raise or illustrate important questions that go beyond the single case and have heuristic value.
- Manuscripts that present or discuss theoretical formulations of psychopathology, or that evaluate competing theoretical formulations on the basis of published data, may also be accepted.

The Journal of Abnormal Psychology publishes articles on basic research and theory in the broad field of abnormal behavior, its determinants, and its correlates.
The following general topics fall within its area of major focus:

- psychopathology — its etiology, development, symptomatology, and course
- normal processes in abnormal individuals
- pathological or atypical features of the behavior of normal persons
- experimental studies, with human or animal subjects, relating to disordered emotional behavior or pathology
- sociocultural effects on pathological processes, including the influence of gender and ethnicity
- tests of hypotheses from psychological theories that relate to abnormal behavior

Thus, studies of patient populations, analyses of abnormal behavior, case histories, and theoretical papers of scholarly substance on deviant personality and emotional abnormality would all fall within the boundaries of the journal's interests.

Each article should represent a significant addition to knowledge and understanding of abnormal behavior in its etiology, development, or description.

In order to improve the use of journal resources, it has been agreed by the two Editors concerned that the Journal of Abnormal Psychology will not consider articles dealing with diagnosis or treatment of abnormal behavior, and the Journal of Consulting and Clinical Psychology will not consider articles dealing with the etiology or descriptive pathology of abnormal behavior.

Therefore, a study that focuses primarily on treatment efficacy should be submitted to the Journal of Consulting and Clinical Psychology. However, a longitudinal study focusing on developmental influences or origins of abnormal behavior should be submitted to the Journal of Abnormal Psychology.

Articles of five different types will be considered for publication in the Journal: Brief Reports, Regular Articles, Extended Articles, Case Studies, and Commentaries.

- Brief Reports must not exceed 5,000 words in overall length. This limit includes all aspects of the manuscript (title page, abstract, text, references, tables, author notes and footnotes, appendices, figure captions) except figures. Brief Reports also may include a maximum of two figures. For Brief Reports, the length limits are exact and must be strictly followed.
- Regular Articles typically should not exceed 9,000 words in overall length (excluding figures).
- Extended Articles are published within regular issues of the Journal (they are not free-standing) and are reserved for manuscripts that require extended exposition beyond the normal length restrictions of a Regular Article. Typically, Extended Articles will report multiple experiments, multifaceted longitudinal studies, cross-disciplinary investigations, or studies that are extraordinarily complex in terms of methodology or analysis. Any submission that exceeds a total of 12,000 words in length automatically will be considered for publication as an Extended Article.
- Case Studies and Commentaries have the same length requirements as Brief Reports.

Cover Letters

All cover letters must contain the following:
• a statement that the material is original — if findings from the dataset have been previously published or are in other submitted articles, please include the following information:
  o Is the present study a new analysis of previously analyzed data? If yes, please describe differences in analytic approach.
  o Are some of the data used in the present study being analyzed for the first time? If yes, please identify data (constructs) that were not included in previously published or submitted manuscripts.
  o Are there published or submitted papers from this data set that address related questions? If yes, please provide the citations, and describe the degree of overlap and the unique contributions of your submitted manuscript.
• the full postal and email address of the corresponding author;
• the complete telephone and fax numbers of the same;
• the proposed category under which the manuscript was submitted;
• a statement that the authors complied with APA ethical standards in the treatment of their participants and that the work was approved by the relevant Institutional Review Board(s);
• whether or not the manuscript has been or is posted on a web site;
• that APA style (Publication Manual, 6th edition) has been followed;
• the disclosure of any conflicts of interest with regard to the submitted work;
• a request for masked review, if desired, along with a statement ensuring that the manuscript was prepared in accordance with the guidelines above.

Authors should also specify the overall word length of the manuscript (including all aspects of the manuscript, except figures) and indicate the number of tables, figures, and supplemental materials that are included.

Manuscript Preparation

Prepare manuscripts according to the Publication Manual of the American Psychological Association (6th edition). Manuscripts may be copyedited for bias-free language (see Chapter 3 of the Publication Manual).

Review APA's Checklist for Manuscript Submission before submitting your article.

Double-space all copy. Other formatting instructions, as well as instructions on preparing tables, figures, references, metrics, and abstracts, appear in the Manual.

Below are additional instructions regarding the preparation of display equations, computer code, and tables.

Display Equations

We strongly encourage you to use MathType (third-party software) or Equation Editor 3.0 (built into pre-2007 versions of Word) to construct your equations, rather than the equation support that is built into Word 2007 and Word 2010. Equations composed with the built-in Word 2007/Word 2010 equation support are converted to low-resolution graphics when they enter the production process and must be rekeyed by the typesetter, which may introduce errors.

To construct your equations with MathType or Equation Editor 3.0:
Go to the Text section of the Insert tab and select Object.
Select MathType or Equation Editor 3.0 in the drop-down menu.

If you have an equation that has already been produced using Microsoft Word 2007 or 2010 and you have access to the full version of MathType 6.5 or later, you can convert this equation to MathType by clicking on MathType Insert Equation. Copy the equation from Microsoft Word and paste it into the MathType box. Verify that your equation is correct, click File, and then click Update. Your equation has now been inserted into your Word file as a MathType Equation.

Use Equation Editor 3.0 or MathType only for equations or for formulas that cannot be produced as Word text using the Times or Symbol font.

Computer Code

Because altering computer code in any way (e.g., indents, line spacing, line breaks, page breaks) during the typesetting process could alter its meaning, we treat computer code differently from the rest of your article in our production process. To that end, we request separate files for computer code.

In Online Supplemental Material
We request that runnable source code be included as supplemental material to the article. For more information, visit Supplementing Your Article With Online Material.

In the Text of the Article
If you would like to include code in the text of your published manuscript, please submit a separate file with your code exactly as you want it to appear, using Courier New font with a type size of 8 points. We will make an image of each segment of code in your article that exceeds 40 characters in length. (Shorter snippets of code that appear in text will be typeset in Courier New and run in with the rest of the text.) If an appendix contains a mix of code and explanatory text, please submit a file that contains the entire appendix, with the code keyed in 8-point Courier New.

Tables

Use Word's Insert Table function when you create tables. Using spaces or tabs in your table will create problems when the table is typeset and may result in errors.

Submitting Supplemental Materials

APA can place supplemental materials online, available via the published article in the PsycARTICLES® database. Please see Supplementing Your Article With Online Material for more details.

Abstract and Keywords

All manuscripts must include an abstract containing a maximum of 250 words typed on a separate page. After the abstract, please supply up to five keywords or brief phrases.
References

List references in alphabetical order. Each listed reference should be cited in text, and each text citation should be listed in the References section.

Examples of basic reference formats:

- **Journal Article:**

- **Authored Book:**

- **Chapter in an Edited Book:**

Figures

Graphics files are welcome if supplied as Tiff or EPS files. Multipanel figures (i.e., figures with parts labeled a, b, c, d, etc.) should be assembled into one file.

The minimum line weight for line art is 0.5 point for optimal printing.

For more information about acceptable resolutions, fonts, sizing, and other figure issues, please see the general guidelines.

When possible, please place symbol legends below the figure instead of to the side.

APA offers authors the option to publish their figures online in color without the costs associated with print publication of color figures.

The same caption will appear on both the online (color) and print (black and white) versions. To ensure that the figure can be understood in both formats, authors should add alternative wording (e.g., "the red (dark gray) bars represent") as needed.

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- An additional $450 for each subsequent figure
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In addition, APA Ethical Principles specify that "after research results are published, psychologists do not withhold the data on which their conclusions are based from other competent professionals who seek to verify the substantive claims through reanalysis and who intend to use such data only for that purpose, provided that the confidentiality of the participants can be protected and unless legal rights concerning proprietary data preclude their release" (Standard 8.14).

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Authors are required to state in writing that they have complied with APA ethical standards in the treatment of their sample, human or animal, or to describe the details of treatment.
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