Schizophrenia Research 206 (2019) 400–406

Contents lists available at ScienceDirect

Schizophrenia Research

journal homepage: www.elsevier.com/locate/schres

Goal-directed planning and action impairments in schizophrenia evaluated in a virtual environment

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ARTICLE INFO

Article history:
Received 14 June 2018
Received in revised form 7 October 2018
Accepted 18 October 2018
Available online 22 November 2018

Keywords:
Goal-directed behavior
Motivation
Cognition
Negative symptoms
Virtual reality

ABSTRACT

Planning and executing goal-directed behaviours are critical final steps in translating motivation into action. Amotivation is a key feature of schizophrenia, but its impact on goal-directed functioning has not been extensively studied in an objective and ecologically valid manner. To address this, we investigated goal-directed planning and action in schizophrenia using a virtual reality task, the Multitasking in the City Test (MCT).
The MCT was administered to 49 outpatients with schizophrenia and 55 healthy controls, and required participants to complete a series of errands in a virtual city. Ability to complete the task as directed was assessed by a performance score based on errands completed and errors committed. Task efficiency was evaluated by the total distance travelled, and an index of path efficiency comparing an optimal route with the traversed route.
Schizophrenia participants had lower performance scores, travelled farther, and had reduced path efficiency compared to healthy controls. Greater distance travelled and lower path efficiency in schizophrenia were related to amotivation. Path efficiency in schizophrenia was also related to neurocognition, including planning ability; notably, this relationship appeared to be independent of the relationship with amotivation.
Individuals with schizophrenia demonstrated impaired goal-directed planning and action in the context of a simulated everyday errands task, both in terms of reduced capacity to complete errands and reduced efficiency in doing so. The latter may manifest as diminished real-world motivated and functional behaviour in patients with schizophrenia and indicates a specific deficit in the execution of planned behaviour.

1. Introduction

Motivation deficits are a critical feature of numerous psychiatric illnesses, and have been consistently linked with poor functional outcome. These deficits have received increasing attention in schizophrenia, with the recognition of amotivation as one of two negative symptom subdomains (the other being diminished emotional expression) (Foussias and Remington, 2010; Messinger et al., 2011). Amotivation in schizophrenia has not only been implicated in directly impacting concurrent and longitudinal community functioning (Chang et al., 2016; Evensen et al., 2012; Faerden et al., 2013; Fervaha et al., 2015b; Foussias et al., 2011; Kiang et al., 2003; Konstantakopoulos et al., 2011; Strauss et al., 2013), but also in influencing or mediating the impact on functioning of other illness features, such as diminished cognitive ability (Fervaha et al., 2014; Foussias et al., 2015; Gard et al., 2009; Green et al., 2012; Nakagami et al., 2008; Strauss et al., 2015).

Delineation of the specific pathways involved in the translation of motivation to the performance of everyday goal-directed behaviours (i.e., realizing motivation into action) is an area of ongoing investigation. Component-wise conceptualization of motivation in schizophrenia has postulated a system wherein hedonic experience and (learned) reward prediction inform and guide the valuation of reward obtainment and effort expenditure associated with achieving a particular outcome, which ultimately culminates in the development and execution of a plan to achieve said outcome (Barch and Dowd, 2010). The framework has been extended to encompass motivation as it pertains to psychopathology in general, based on parallels with the Research Domain Criteria (RDoC) initiative's Positive Valence System, in which the development and execution of a plan towards a desirable outcome has been paralleled to "action selection/preference-based decision-making" (Barch et al., 2016). Despite recognition of planning and execution of goal-directed behaviour as a critical component of this pathway,

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https://doi.org/10.1016/j.schres.2018.10.012
0920-9964/

objective and ecologically valid examination of this specific aspect of motivated behaviour in schizophrenia has been lacking.

Previous investigations of distinct aspects of motivation in schizophrenia have included relevant assessments of action selection and decision-making, specifically in the context of effort-cost decision-making and reward-driven decision-making using a variety of laboratory-based objective paradigms. Effort-cost decision-making tasks, wherein varying magnitudes of reward are offered for varying magnitudes of physical or cognitive effort, have associated schizophrenia patients' reduced effort expenditure with negative symptoms or amotivation, and in some cases identified diminished effort in patients compared to healthy controls (Barch et al., 2014; Docx et al., 2015; Fervaha et al., 2015a, 2013; Gold et al., 2013; Hartmann et al., 2015; Horan et al., 2015; Reddy et al., 2015; Strauss et al., 2016; Treadway et al., 2015; Wolf et al., 2014). Patients with schizophrenia also show impairments in reward-driven decision-making tasks, wherein choices to optimize reward are made in the face of inferred or indicated probabilities of gains or losses (Fond et al., 2013; Heerey et al., 2008; Kim et al., 2012; Lee et al., 2007; Shurman et al., 2005; Yip et al., 2009); recent findings suggest deficiencies in integrating outcome frequency and magnitude information manifest as impaired decision-making (Albrecht et al., 2016; Brown et al., 2015; Kim et al., 2016). While these investigations have been instrumental in identifying impairments in specific aspects of motivation that guide the formulation and execution of strategies in pursuit of desired outcomes, it remains unclear whether these impairments generalize to real-world behaviours. The tasks employed, due to their abstract nature, are somewhat removed from circumstances individuals encounter outside laboratory settings. The use of ecologically valid test measures may be particularly important for the component of motivation encompassing planning and execution of goal-directed behaviour, as this component constitutes the critical final steps of realizing motivation into action, leading to behavioural responses that ultimately determine one's functioning on a day-to-day basis.

The utility of objective test measures with greater semblance to real-world scenarios has been demonstrated by previous investigations that have focused on the impact of cognitive deficits on functional behaviour in schizophrenia. Virtual environments have been employed to assess functional capacity, centered around shopping and related activities (Aubin et al., 2015; Greenwood et al., 2016; Josman et al., 2009; Keefe et al., 2016). Virtual reality-based tasks have also been designed to assess cognitive flexibility (Han et al., 2012), navigation abilities (Weniger and Irle, 2008; Zawadzki et al., 2013), and medication management (Kurtz et al., 2007). Such application of virtual reality technology has allowed the emulation of naturalistic scenarios to evaluate behaviour in response to realistic cognitive demands that individuals may face in the real-world, in contrast to demands presented by abstract tasks. A similar approach may be beneficial for the evaluation of planning and execution of goal-directed behaviour in the context of motivation deficits in schizophrenia, to complement what has been gleaned from previous investigations that have relied on the use of abstract tasks and clinical rating instruments.

Accordingly, the current study utilized a virtual reality goal planning and action task, the Multitasking in the City Test (MCT), in which participants complete a series of specified errands in a virtual city. The MCT has been previously used in healthy adults and patients with acquired brain injury as an ecologically valid test measure of everyday goal-directed functioning (Jovanovski et al., 2012a, 2012b). We hypothesized that patients with schizophrenia would demonstrate impaired goal-directed behaviour in the MCT compared to healthy controls, specifically based on the completion of errands and the efficiency of task completion. Further, we predicted that behavioural measures of the MCT would correlate specifically with clinical measures of amotivation and community functioning.

2. Methods

2.1. Participants

Forty-nine patients with schizophrenia or schizoaffective disorder (SZ) recruited from outpatient clinics and 55 healthy control subjects (HC), group-matched for age (within 5 years) and sex (within 5%), completed the study. Participants were aged 18 to 55 years, with no history of active substance abuse or dependence in the past 3 months (except for nicotine) or neurological disease. SZ participants met the following inclusion criteria: DSM-IV diagnosis of schizophrenia or schizoaffective disorder (and no other concurrent Axis I disorder) based on the Mini International Neuropsychiatric Inventory (MINI) (Sheehan et al., 1998); stable dose of antipsychotic medications for at least four weeks; capable to consent to participate in the study based on the MacArthur Competency Assessment Tool for Clinical Research (MacCAT-CR) (Appelbaum and Grisso, 2001); and absence of significant akathisia (global item <3 on the Barnes Akathisia Rating Scale (Barnes, 1989)) or extrapyramidal symptoms (ratings >2 on at most 2 items on the Simpson Angus Rating Scale (SAS) (Simpson and Angus, 1970)). HC participants did not meet criteria for any Axis I disorder, and had no family history of schizophrenia or related psychotic disorder in a first-degree relative. This study was approved by the local institutional research ethics board, and all participants provided written informed consent.

2.2. Clinical measures

All participants were administered the Scales for the Assessment of Positive Symptoms and Negative Symptoms (SAPS and SANS) (Andreasen, 1984, 1982) to assess overall positive and negative symptom severity. SAPS total scores were computed with the exclusion of global items, and SANS total scores were computed with the exclusion of global items and the Attention subscale. SANS subdomain scores were computed for Diminished Expression (sum of Poverty of Speech and Affective Flattening subscale items, excluding global and Inappropriate Affect items) and Amotivation (sum of Avolition-Apathy and Anhedonia-Asociality subscale items, excluding global items) (Foussias et al., 2009). Amotivation was also assessed with the Apathy Evaluation Scale – clinical version (AES) (Marin et al., 1991) and the Intrinsic Motivation subscale of the Quality of Life Scale (QLS) (Heinrichs et al., 1984; Nakagami et al., 2008). The total scores from these three measures of amotivation were combined to form a single regression-weighted composite amotivation score using a principal components analysis with varimax rotation (Foussias et al., 2015). Depressive symptoms were assessed with the Calgary Depression Scale for Schizophrenia (CDSS) (Addington et al., 1990). Participants were also administered the Brief Assessment of Cognition in Schizophrenia (BACS) (Keefe et al., 2004); the Tower of London Z-scores, Token Motor Task Z-scores, and composite Z-scores, each determined using age and sex normative data, served as measures of planning ability, motor speed, and global neurocognition, respectively; we also computed the mean of Z-scores of all tests except the Tower of London to assess global neurocognition excluding planning ability. Community functioning was assessed using the QLS total score, with the exclusion of the Intrapsychic Foundations subscale. Chlorpromazine dose equivalents were calculated for SZ participants' antipsychotic medications (Gardner et al., 2010; Leucht et al., 2016), and the SAS was used to assess medication-induced motor side-effects.

2.3. The Multitasking in the City Test (MCT)

A detailed description of the MCT, including specific instructions provided to participants (Jovanovski et al., 2012a, Appendix), screen captures of the task as it appears to participants (Jovanovski et al., 2012a, Fig. 2), and a schematic map of the virtual environment (Jovanovski et al., 2012a, Fig. 1), have been published previously (Jovanovski et al., 2012a). Briefly, the MCT requires participants to navigate in a virtual city using a joystick controller and complete eight prespecified errands (e.g., shopping and budgeting for expenses, withdrawing money from a bank machine, attending appointments, and going to the post office) with the aim of completing all errands within 15 min. Participants are provided initial training within the city to become familiar with the layout of the city and stores, after being provided a map of the city and a list of the required errands that they can refer to throughout (although without the ability to complete any errands during the training phase). Following training, participants are provided unlimited time to construct a plan of action for completing the required errands; participants may use the map and list of errands for this planning period, and are additionally provided a pen, but are not provided any specific guidance beyond being instructed that they now have some time to plan their actions for the task. After this planning period, participants are administered the MCT. During the test participants are still able to refer to the map, and the required errands (those completed and those remaining) are shown on-screen to lessen working memory load.

Although the task itself and the task administration procedures for the current study were identical to the same for the original studies that used the MCT (Jovanovski et al., 2012a, 2012b), the current study diverges from the prior investigations with regards to the task outcome measures. Unlike in the studies conducted by Jovanovski and colleagues, we did not evaluate the planning phase as part of MCT performance, but instead focused on behaviour demonstrated solely during the main task phase. All MCT measures computed for the current study were derived from raw data that are directly monitored and recorded by the task software, with no reliance on video recordings of screen activity, allowing for more streamlined processing that does not involve human raters. The raw data output from task runs, including details of errand completion attempts and in-task position and heading data for the full task duration, were processed using MATLAB version R2013a/8.1.0.604 (The MathWorks, Inc., Natick, MA). These data were used to compute the number of errands successfully completed, as well as the number of errors committed within three categories of errors: failed attempt (i.e., unsuccessful attempt at errand completion – e.g., attempting to make a purchase without sufficient funds, or attempting to complete a time-specific errand past its deadline), repeated completion (i.e., successful completion of an errand already completed), and unnecessary store entry (i.e., entering a store that was not associated with any errand, or entering an errand-associated store more than once). These were subsequently combined into a single score to serve as a primary task outcome measure of performance (henceforth termed "Performance Score"): 1 point was awarded for each errand successfully completed, and 0.5 points were deducted for each error committed. We devised Performance Score to be a composite indicator of ability to complete the task as directed, encompassing elements of task performance that were captured as several separate variables in the original MCT studies.

For a more comprehensive understanding of behaviour in MCT, we additionally examined individuals' route of travel in the course of completing the specified errands. To this end, total distance travelled within the virtual environment across the full task duration served as an indicator of task efficiency, and was used as another primary task measure (henceforth referred to as "Distance Travelled"). While total distance travelled presents a general representation of efficiency, it is important to consider how distance travelled is influenced by the manner in which participants completed (or attempted to complete) errands – the use of Distance Travelled as the sole measure of efficiency may be misleading, considering that it can be decreased by missing (i.e., failing to attempt) errands and increased by attempting errands in a suboptimal order or by committing errors. To therefore explore route of travel further, we computed an index of path efficiency (henceforth referred to as "Path Efficiency") based on methods that have been commonly used to quantify path tortuosity in non-human animals. In particular, the efficiency of a whole path comprised of discrete steps (i.e., movements between successively visited locations) can be quantified by the ratio $\sum D_i / \sum L_i$, where D_i is the beeline distance and L_i is the subject's path length between two successively visited locations (Benhamou, 2004). For the MCT, we adopted this approach to compute Path Efficiency as the ratio between the optimal whole path length (the counterpart of $\sum D_i$) and total distance travelled (the counterpart of $\sum L_i$):

$$\textit{Path Efficiency} = \frac{\textit{Optimal whole path length}}{\textit{Distance Travelled}}$$

As store boundaries prohibit straight-line traversal, the shortest possible path between two successively visited errand locations was determined using an implementation of the A* ("A star") pathfinding algorithm in MATLAB (Ueland et al., 2017), and the lengths of these path segments were subsequently summed to determine the optimal whole path length. The optimal path computation for a participant included the locations of all of the participant's errand attempts (successful or erroneous) in the order attempted; the optimal whole path length was therefore not necessarily the same across all participants. Path Efficiency thus represents the proportion of total distance travelled that can be accounted for by errand completion attempts with consideration to the order of completion and interspersed errors therein, and therefore provides a measure of route efficiency that, (potentially) unlike Distance Travelled, is not conflated with elements of task behaviour subsumed under Performance Score.

2.4. Statistical analysis

Statistical analyses were performed using SPSS Statistics version 24.0 (IBM Corp., Armonk, NY). Demographic and clinical characteristics were compared between SZ and HC groups using chi-square or independent samples *t*-tests, as appropriate. Performance Score, Distance Travelled, and Path Efficiency were also initially compared between groups using *t*-tests. Pearson correlations were used to evaluate associations between the MCT measures and all clinical measures in the SZ group, as well as in the HC group. Partial correlations were performed when MCT measures correlated with any clinical measure except those for amotivation, cognition, or community functioning. Further, if potentially confounding associations were detected, the aforementioned group comparisons of MCT measures were re-evaluated with the appropriate covariate using univariate analyses of covariance (ANCOVAs).

3. Results

3.1. Group comparisons of clinical and MCT measures

Clinical characteristics of the SZ and HC groups are summarized in Table 1, and include the composite measure of amotivation. The principle components analysis for this measure yielded a single extracted component with an eigenvalue >1, which accounted for 75.4% of the variance, with each constituent clinical measure having a loading of at least 0.86. This score was unavailable for one HC participant due to missing QLS data. The following data were also unavailable: the duration of illness for one SZ participant, the chlorpromazine dose equivalent for one SZ participant, and the BACS composite Z-score (as well as the mean of Z-scores of all tests except the Tower of London) for one HC participant. Summaries of the MCT measures are also presented in Table 1. Initial group comparisons of these measures indicated that Performance Score was significantly lower in SZ compared to HC ($t(64.842) = -3.201$, $p = 0.002$, $d = -0.641$), whereas Distance Travelled was significantly higher ($t(70.639) = 3.529$, $p = 0.001$, $d = 0.705$). Initial examination of Path Efficiency indicated that optimal

Table 1
Characteristics of the study sample, and summaries of Multitasking in the City Test (MCT) behavioural measures.

	SZ (n = 49) Mean (SD)	HC (n = 55) Mean (SD)	Group difference p (Chi-square/*t*-test)
Age (years)	37.8 (10.7)	35.2 (11.4)	ns
Sex (M:F)	29:20	34:21	ns
Illness duration (years)	14.5 (10.0)		
CPZ equivalents (mg)	421.7 (261.4)		
SAPS	12.9 (12.6)		
SANS	13.5 (8.6)	2.4 (3.9)	<0.001
SANS-DimExp	5.6 (4.9)	1.0 (2.4)	<0.001
SANS-Amot	7.9 (6.0)	1.4 (2.4)	<0.001
AES	34.6 (6.9)	29.2 (5.3)	<0.001
QLS	3.3 (1.0)	5.0 (0.8)	<0.001
QLS-IM	3.5 (1.3)	5.0 (1.0)	<0.001
Amotivation	0.62 (1.00)	−0.56 (0.60)	<0.001
BACS composite	−1.24 (1.16)	0.26 (1.14)	<0.001
BACS-TMT	−0.92 (1.42)	0.35 (0.87)	<0.001
BACS-ToL	−0.31 (1.26)	−0.02 (0.97)	ns
BACS-ExclToL	−0.85 (0.71)	0.20 (0.74)	<0.001
CDSS	2.6 (2.6)		
SAS	1.9 (2.1)		
Performance Score	5.6 (2.3)	6.7 (1.0)	0.002
Errands completed	7.5 (0.9)	8.0 (0.1)	0.001
Errors committed	3.9 (3.5)	2.5 (2.0)	0.022
Distance Travelled	394.6 (140.2)	315.7 (73.5)	0.001
Path Efficiency	0.62 (0.16)	0.70 (0.13)	0.006

SZ, schizophrenia group; HC, healthy control group; ns, nonsignificant.
CPZ, chlorpromazine dose; SAPS, Scales for the Assessment of Positive Symptoms; SANS, Scales for the Assessment of Negative Symptoms (DimExp, Diminished Expression subdomain; Amot, Amotivation subdomain); AES, Apathy Evaluation Scale; QLS, Quality of Life Scale (IM, Intrinsic Motivation subscale); BACS, Brief Assessment of Cognition in Schizophrenia (TMT, Token Motor Task; ToL, Tower of London; ExclToL, mean of all tests except Tower of London) Z-score; CDSS, Calgary Depression Scale for Schizophrenia; SAS, Simpson Angus Rating Scale.

Table 2
Correlations and partial correlations (r) between Multitasking in the City Test (MCT) behavioural measures and clinical measures in the schizophrenia sample (n = 49).

	Performance Score	Distance Travelled	Path Efficiency
Age	**−0.36***	**0.40****	**−0.57****
Illness duration	**−0.35***	**0.42****	**−0.50****
CPZ equivalents	−0.06	0.09	−0.06
SAPS	−0.06	0.18	−0.27
SANS	0.00	0.07	−0.15
SANS-DimExp	−0.01	−0.06	0.08
Amotivation	−0.08	**0.34***	**−0.43****
QLS	0.05	−0.22	0.25
BACS composite	0.24	−0.22	0.26
BACS-TMT	0.02	0.06	−0.04
BACS-ToL	0.17	−0.12	0.17
BACS-ExclToL	0.22	−0.22	0.27
CDSS	0.01	−0.07	−0.04
SAS	**−0.30***	0.24	**−0.39****
Illness duration[a]	−0.08	0.15	−0.04
Amotivation[a]	−0.01	0.28	**−0.42****
QLS[a]	0.05	−0.23	**0.30***
BACS composite[a]	0.25	−0.25	**0.34***
BACS-ToL[a]	0.23	−0.19	**0.31***
BACS-ExclToL[a]	0.20	−0.22	**0.30***
Amotivation[b]	0.06	0.24	**−0.37***
QLS[b]	0.04	−0.23	**0.31***

CPZ, chlorpromazine dose; SAPS, Scales for the Assessment of Positive Symptoms; SANS, Scales for the Assessment of Negative Symptoms (DimExp, Diminished Expression subdomain); QLS, Quality of Life Scale; BACS, Brief Assessment of Cognition in Schizophrenia (TMT, Token Motor Task; ToL, Tower of London; ExclToL, mean of all tests except Tower of London) Z-score; CDSS, Calgary Depression Scale for Schizophrenia; SAS, Simpson Angus Rating Scale.
* $p < 0.05$.
** $p < 0.01$.
[a] Controlled for Age and SAS.
[b] Controlled for Age, SAS, and BACS composite.

path length accounted for, on average, 62% and 70% of total distance travelled in SZ and HC, respectively, and that this difference was statistically significant ($t(93.468) = -2.826$, $p = 0.006$, $d = -0.558$).

Due to significant correlations between all MCT measures and age in the SZ group and between Path Efficiency and age in the HC group (detailed in Section 3.2), despite the two groups being matched for age, group differences in task measures were re-evaluated with age as a covariate. In the respective ANCOVAs, group differences were statistically significant for Performance Score ($F(1,101) = 9.613$, $p = 0.003$, $\eta^2 = 0.087$), Distance Travelled ($F(1,101) = 11.662$, $p = 0.001$, $\eta^2 = 0.104$), and Path Efficiency ($F(1,101) = 6.659$, $p = 0.011$, $\eta^2 = 0.062$).

3.2. Clinical correlates of MCT performance

Correlations between the MCT measures and all clinical measures in the SZ group are presented in Table 2. Amotivation was correlated positively with Distance Travelled and negatively with Path Efficiency, but was not significantly correlated with Performance Score. However, all MCT measures were also correlated with age and illness duration, and Performance Score and Path Efficiency were also correlated with the SAS. After controlling for age and the SAS, amotivation was correlated only with Path Efficiency, which also correlated with the QLS, BACS composite Z-score, BACS Tower of London Z-score, and the mean of BACS Z-scores of all tests except the Tower of London. To investigate whether amotivation uniquely accounted for variation in Path Efficiency, we additionally controlled for the BACS composite Z-score; amotivation and Path Efficiency remained significantly correlated. These partial correlations are also presented in Table 2.

In the HC group, no clinical measure was correlated with Performance Score. The BACS composite Z-score was correlated with Distance Travelled ($r = -0.330$, $p = 0.015$) and Path Efficiency ($r = 0.422$, $p = 0.001$). The BACS Tower of London Z-score specifically also correlated with Distance Travelled ($r = -0.303$, $p = 0.025$) and Path Efficiency ($r = 0.410$, $p = 0.002$). The mean of BACS Z-scores of all tests except the Tower of London was also similarly correlated with Distance Travelled ($r = -0.315$, $p = 0.020$) and Path Efficiency ($r = 0.395$, $p = 0.003$). However, Path Efficiency was also correlated with age ($r = -0.363$, $p = 0.006$). The aforementioned correlations between Distance Travelled, Path Efficiency, BACS composite Z-score, BACS Tower of London Z-score, and the mean of BACS Z-scores of all tests except the Tower of London remained significant in the partial correlations controlled for age ($|r| = 0.314$–0.470, $p \leq 0.021$). No clinical measure was correlated with any MCT measure after additionally controlling for the BACS composite Z-score in the HC group.

4. Discussion

In this particular study, we employed a previously validated virtual goal-directed functioning task to assess ability to plan and execute goal-directed behaviour in schizophrenia. The MCT bears greater semblance to what individuals may experience on a daily basis compared to existing clinical and task-based examination of motivation, thereby allowing quantification of deficits in translating plans into actions, as well as how these deficits relate to clinically assessed motivation, cognition, and community functioning.

Group differences between SZ and HC in the MCT measures, with and without controlling for age, demonstrate the task's capacity to discriminate behavioural deficits in individuals with schizophrenia from healthy counterparts. In particular, significantly lower Performance Score and higher Distance Travelled in SZ compared to HC indicate diminished capability in our SZ sample to complete the task as directed, as well as greater difficulty in doing so in an efficient manner. Further, the significant difference in Path Efficiency indicates that greater Distance Travelled in the SZ group was not simply due to errand completions and errors subsumed under Performance Score; SZ participants demonstrated reduced efficiency compared to HC even after equalizing the impact of successful and unsuccessful errand completion attempts. Previous investigations using virtual reality tasks of grocery shopping and related activities have reported performance impairments in schizophrenia patients compared to controls (Josman et al., 2009; Keefe et al., 2016), and our findings using the MCT suggest that such deficits extend to planning and execution of a more diverse assortment of goal-directed behaviours in a simulated naturalistic setting.

Despite the significant difference between groups, Performance Score was not significantly correlated with cognition or amotivation in the SZ or HC group, suggesting that individuals' deficiencies in ability to complete the MCT as directed were not attributable to cognitive difficulties, and that such deficiencies are not representatively reflected by clinical assessments of amotivation that aim to capture a broad array of demonstrable behavioural deficits. Cognition was, however, correlated with task efficiency, particularly with Path Efficiency in the SZ group (after controlling for age and medication side-effects), and with both Distance Travelled and Path Efficiency in the HC group; these associations appeared to be driven by planning ability (as measured by the BACS Tower of London task), as well as other aspects of cognition (e.g., working memory and processing speed) that comprise general cognitive ability (as measured by the mean of BACS *Z*-scores of all tests except the Tower of London). Thus, while planning and general cognitive ability appeared to ubiquitously contribute to task efficiency in the HC group (i.e., correlating with both Distance Travelled and Path Efficiency), its contribution in the SZ group appeared to be limited, evident only after abstracting the impact of errand completion attempts (i.e., correlating with Path Efficiency, but not Distance Travelled).

Another point of discrepancy between the SZ and HC groups is that amotivation was associated with the measures of efficiency only in the SZ group. Higher amotivation was significantly correlated with increased Distance Travelled and reduced Path Efficiency, albeit with the relationships potentially being confounded by coincident associations with age, illness duration, and medication side-effects. The association between amotivation and Path Efficiency was particularly prominent and highlights a deficit distinctly in motivated behaviour, as this correlation remained significant after controlling for global cognition and potentially confounding factors. A similar association between community functioning and Path Efficiency suggests that inability to execute a plan efficiently may manifest as deficits not only in observable behaviours that inform clinical assessments of amotivation, but also in a wider scope of functional behaviours that are central to schizophrenia patients' overall well-being.

Interestingly, these findings for the efficiency measures do not indicate reduction in behavioural output in the MCT in relation to amotivation in schizophrenia, but quite the opposite; the aforementioned group differences in these measures also seem to implicate greater behavioural arousal rather than inhibition in SZ compared to HC. Motivation is a complex process comprised of both “activational” (i.e., behavioural arousal) and “directional” (i.e., goal-directed action) components (Salamone et al., 2016; Simpson and Balsam, 2016), and in this respect SZ participants appeared to demonstrate a deficiency in the latter component, resulting in behaviour that is excess to achieving the goal of completing a series of specific errands. Previous investigations have also identified behavioural inefficiency in schizophrenia, specifically in the context of effort-cost decision-making, wherein patients appear to allocate effort suboptimally towards obtaining monetary rewards (Barch et al., 2014; Fervaha et al., 2013; Gold et al., 2013), leading to the proposition that patients with schizophrenia demonstrate deficiency in allocating effort effectively, but not necessarily in expending effort outright (Whitton et al., 2015). Although neither the MCT nor effort-cost decision-making tasks can assess the broad construct of motivation as a whole, the consistency of these findings suggests that goal-directed action inefficiency makes considerable contribution to motivation deficits that are central to this illness.

It is also interesting to note that Path Efficiency's relationship with amotivation in our schizophrenia sample appears to be independent of its relationships with cognition and planning ability, as the relationship with amotivation persisted after controlling for global cognition (including planning ability). Such independence suggests Path Efficiency in the MCT may provide important insights into impairments in planning and execution of goal-directed behaviour in schizophrenia, particularly as a potential means of distinguishing the “planning” and “execution” aspects of this critical component of the pathway of motivated behaviour. Within this context, the MCT involves distinct elements of planning (e.g., deciding/selecting which errand to complete next) and executing behaviour (e.g., navigating towards and thereafter completing the selected errand). Assuming that the manner in which an individual attempts to complete the MCT (i.e., the individual's series of errand completion attempts) is representative of the individual's plan of action that evolves dynamically as the task progresses, the optimal path computed for Path Efficiency represents the contribution of said plan to the total distance travelled. Under this assumption, then, the complement of Path Efficiency (i.e., 1 – Path Efficiency, or “Path Inefficiency”) represents task behaviour that it attributable to the execution of an overall plan (including any errors), rather than the plan itself. The aforementioned significant group difference between SZ versus HC and clinical correlations in SZ with Path Efficiency (which also apply for Path Inefficiency, albeit in the opposite direction) therefore suggests there is a specific impairment in the execution of planned behaviour in patients with schizophrenia that relates to diminished motivated behaviour, beyond what can be accounted for by deficits in planning and cognitive ability. Considering that previous task-based investigations have identified decision-making impairments in schizophrenia, our findings for Path Efficiency in the MCT suggest that schizophrenia patients' performance of functional activities may be hindered not only by impairments in motivated decision-making abilities (based on findings from previous investigations discussed in the Introduction), but also by inefficiencies in enacting behaviours that ensue from said decisions. As the MCT was not specifically designed to disentangle and distinctly assess planning versus execution, this phenomenon requires additional, more dedicated investigation to further our understanding of deficits in goal-directed behaviour in schizophrenia.

An important consideration for the MCT, and indeed any virtual reality-based task that allows participants to navigate freely with a joystick, is the potential impact of prior exposure to video games and joysticks on task performance. We attempted to minimize the impact of such prior exposure by employing a fairly simple control scheme, and allowing participants to become familiar with said scheme in a training session. Further, the lack of any significant correlation between the MCT measures and the BACS Token Motor Task suggests that task behaviour was not significantly associated with motor ability. Nonetheless, the lack of an objective measure that specifically quantifies proficiency of joystick usage is a limitation of this study. Another potential limitation is that all SZ participants in our sample were receiving treatment with antipsychotic medication (a consequence of our focus on stable community-dwelling outpatients), and although the MCT measures were not associated with medication dosage, some measures correlated significantly with medication side-effects (despite restrictions that excluded participants with severe motor side-effects). We attempted to address these limitations by controlling for the SAS in our statistical analyses, where appropriate, and followed a similar approach for other potentially confounding factors, namely age.

In summary, the MCT provides an objective and ecologically valid means of evaluating planning and executing goal-directed behaviour in schizophrenia that is particularly sensitive to patients' deficits in capacity to fulfil simulated everyday tasks, and in applying motivation and cognitive abilities to do so in an efficient manner. While task metrics showed the expected relationships with motivation and cognition, substantial unaccounted variance potentially reflects the MCT's ability to assess aspects of goal planning and action that are beyond the scope of standard clinical assessment tools. The MCT may ultimately facilitate rapid assessment of how individuals with schizophrenia translate plans into actions in the real world, and provide insights into how this translation is affected by illness symptomatology.

Conflicts of interest

GR has received consultant fees from Neurocrine Biosciences and Synchroneuron, as well as research support from Novartis. GFo has served as an investigator on research sponsored by Medicure Inc. and Neurocrine Bioscience, has served on advisory boards for Hoffman-La Roche and Takeda, and has received speaker's fees from Hoffman-La Roche, Lundbeck, and Novartis. The other authors have no conflicts of interest to disclose.

Contributors

GR and GFo designed the study. IS undertook the statistical analysis and prepared the first draft of the manuscript. All other authors subsequently contributed significantly to the interpretation of the findings, reviewed the manuscript, and have approved the final manuscript.

Funding

This work was supported by the Schizophrenia Society of Ontario, an American Psychiatric Association-AstraZeneca Young Minds in Psychiatry Award to GFo, and a Frederick Banting and Charles Best Canada Graduate Scholarships Doctoral Award (CGS-D) from the Canadian Institutes of Health Research (CIHR) to IS. The funding sources had no contribution to the design and conduct of the study, in the collection, analysis, and interpretation of the data, or in the preparation, review, and approval of the manuscript.

Acknowledgements

We thank S. Thavabalasingham, N. Hassan, C. Plagiannakos, and K. Mc Donald for their contributions to data collection. We also thank the participants of this study.

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