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Empirically Defined Patterns of Executive Function Deficits in Schizophrenia and Their Relation to Everyday Functioning: A Person-Centered Approach

Mary Iampietro, **Tania Giovannetti**, **Deborah A. G. Drabick**, and **Rachel K. Kessler**
Temple University, Philadelphia, PA, USA

Abstract

Executive function (EF) deficits in schizophrenia (SZ) are well documented, although much less is known about patterns of EF deficits and their association to differential impairments in everyday functioning. The present study empirically defined SZ groups based on measures of various EF abilities and then compared these EF groups on everyday action errors. Participants (n=45) completed various subtests from the Delis–Kaplan Executive Function System (D-KEFS) and the Naturalistic Action Test (NAT), a performance-based measure of everyday action that yields scores reflecting total errors and a range of different error types (e.g., omission, perseveration). Results of a latent class analysis revealed three distinct EF groups, characterized by (a) multiple EF deficits, (b) relatively spared EF, and (c) perseverative responding. Follow-up analyses revealed that the classes differed significantly on NAT total errors, total commission errors, and total perseveration errors; the two classes with EF impairment performed comparably on the NAT but performed worse than the class with relatively spared EF. In sum, people with SZ demonstrate variable patterns of EF deficits, and distinct aspects of these EF deficit patterns (i.e., poor mental control abilities) may be associated with everyday functioning capabilities.

Keywords

Executive function; Schizophrenia; Everyday action; Latent class analysis

INTRODUCTION

Impairments in executive functions have been well documented among people with schizophrenia (e.g., Heinrichs, 2005). These cognitive deficits may precede the emergence of other clinical symptoms (Rajji & Mulsant, 2008; Reichenberg et al., 2010) and have been linked to a wide range of adaptive functions, including self-awareness (Lysaker & Lysaker, 2001), psychosocial skills, social problem solving and social attainment, and occupational and everyday functioning (Green, Kern, Braff, & Mintz, 2000). The present study focused on the relation between executive functions and the completion of everyday tasks. Because executive function is a multidimensional construct, it is crucial to understand the patterns of executive deficits among people with schizophrenia and the potential impact of differential executive deficits on the completion of everyday tasks. Such knowledge could advance the development of behavioral intervention strategies, especially considering that cognitive deficits do not improve with the current pharmaceutical interventions available for

Address correspondence to: Tania Giovannetti, Psychology Department, Temple University, 1701 North 13th Street, Philadelphia, PA 19122, USA. tgio@temple.edu.

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schizophrenia. The aim of this study was to characterize the executive deficits of patients with schizophrenia using a person-centered analytic approach and to subsequently examine whether individuals with different executive deficit patterns exhibit different everyday functioning capabilities.

Executive function (EF) is an umbrella term used to describe multiple cognitive functions associated with the prefrontal cortex (PFC) and its subcortical projections (Mega & Cummings, 1994; Miller & Cohen, 2001), including planning actions towards a goal, flexibility, sequencing, fluency, switching, inhibition, concept formation, estimation, prediction, and maintaining attentional set (e.g., Banich, 2004). Although these specific abilities are generally accepted as executive functions, there is debate regarding whether these abilities are separable or overlapping processes (e.g., Hedden & Yoon, 2006; Hull, Hamilton, Martin, Beier, & Lane, 2008; Miyake et al., 2000).

In an effort to reconcile this debate, investigators have attempted to meaningfully group executive functions using variable-centered statistical methods. In one of the most frequently cited studies on this topic, Miyake et al. (2000) identified three separable executive processes of shifting, updating/monitoring, and inhibition using confirmatory factor analysis with data from healthy college undergraduates. The “shifting” or “switching” construct refers to an individual’s ability to alternate between task demands or mental sets. For example, skilled switching is essential for one to flawlessly alternate between cooking a meal and checking one’s email. Updating/monitoring requires an individual to actively and dynamically manipulate information in working memory. This process is utilized, for example, when one mentally calculates the change he/she is owed after a purchase. Inhibition refers to an individual’s ability to intentionally override the tendency to produce a prepotent or more dominant response when a nondominant response is required. For instance, inhibition allows one to alter his/her usual route home from work in order to perform a relatively infrequent errand.

Subsequent studies incorporated different participant populations and executive measures and supported the overarching hypothesis that executive functions include distinct, separable cognitive processes, but there has been considerable variability in the specific executive components reported across studies. In a study of older adults, Hull et al. (2008) identified only two distinct factors, “shifting” and “updating,” using confirmatory factor analysis. Hedden and Yoon (2006) identified distinct subcomponent processes of “shifting/updating” and “resistance to proactive interference” using a different set of executive measures with a sample of older adults.

In addition to factor analytic methodologies, studies of discrete brain lesions (Stuss et al., 2002) and functional neuroimaging (see Bledowski, Kaiser, & Rahm, 2010; Cabeza & Nyberg, 2000, for reviews) also have contributed to efforts to meaningfully parse executive functions. Stuss et al. (2002) identified two underlying executive processes of “task setting” and “monitoring” in people with PFC lesions. Others have suggested that executive function deficits may fractionate according to sensory or output modalities (Hamilton & Martin, 2005; cf., Hull et al., 2008). Most functional neuroimaging studies show functional specificity for discrete executive functions in the PFC (cf., Duncan et al., 2000; Ghering & Knight, 2002; Wagner, Maril, Bjork, & Schacter, 2001); however, there is great variability in specific findings, as well as theoretical models and cognitive tasks, across studies. Few single lesion or neuroimaging studies have attempted to differentiate the role of the PFC in all three of the aforementioned executive components: shifting, updating/monitoring, and inhibition. Thus, although there is currently no consensus regarding the precise neural substrates of these functions, research generally supports models of specific and discrete executive function abilities, regardless of their nebulous boundaries.

Most relevant to the current study are reports of executive function components in people with schizophrenia. Chan, Chen, Cheung, Chen, and Cheung (2006) found that 27.8% of patients with chronic schizophrenia performed poorly on all executive measures in a protocol of 19 tests chosen to represent five distinct executive functions. Fewer patients (5.6%) exhibited intact or fair performance on all measures. The remaining sample demonstrated fair or intact performance on one (8.9%), two (16.7%), three (21.1%), or four (10%) measures of various executive components. A second study of first-episode, medication-naïve patients with schizophrenia also found variable executive function performance, ranging from intact to impaired, on all component executive function measures (Chan, Chen, & Law, 2006). These studies suggest variability in terms of the *severity* of the executive deficits in schizophrenia, but they do not speak to potential qualitative differences in executive deficits (e.g., differences in the type of deficits) or distinct *patterns* of executive deficits (e.g., differences in severity *and* type of deficits) across individuals.

Studies examining specific executive deficit patterns in people with schizophrenia have focused on a wide range of executive constructs. The constructs of goal maintenance (i.e., activating and sustaining task-related goals) and interference control were identified as central, circumscribed executive processes following an extensive literature review and discussion at the initial meeting of the Cognitive Neuroscience Treatment Research to Improve Cognition in Schizophrenia (CNTRICS) group (Barch & Smith, 2008). Empirical studies have identified different constructs. Chan, Chen, Cheung, and Cheung (2004) conducted a factor analysis using complex measures of executive function and reported three distinct factors: semantic inhibition, action/attention inhibition, and output generation. A recent study by Clark, Warman, and Lysaker (2010) used exploratory factor analysis in an outpatient sample of individuals with schizophrenia and identified two separate executive function components of inhibition/set shifting and mental flexibility. Another recent study by Savla et al. (2011) examined differences between people with schizophrenia and healthy controls on executive measures from the Delis–Kaplan Executive Function System (D-KEFS; Delis, Kaplan, & Kramer, 2001) and concluded that patients with schizophrenia may be particularly impaired in the mental control and manipulation processes required for the Trail Making Test; difficulties on more complex executive measures of task switching were better explained by lower level deficits, such as inattention or slowed processing speed. Taken together, these studies support the notion of discrete executive components, but their results provide no consensus on the nature of these specific, discrete components. These studies also offer little insight into differential executive deficit patterns across *individuals* with schizophrenia (Rajji & Mulsant, 2008). Person-centered approaches are essential to identify similarities and differences in severity and type of executive deficit patterns across individuals.

As stated earlier, understanding whether individuals with schizophrenia can be grouped differently based on their executive deficit patterns may elucidate functional outcomes in this population (Kessler, Giovannetti, & MacMullen, 2007; Semkovska, Bedard, Godbout, Limoge, & Stip, 2004; Vaughan & Giovanello, 2010). Recent findings show that everyday action difficulties may vary across individuals with different patterns of cognitive deficits (Giovannetti, Schmidt, Sestito, Libon, & Gallo, 2006; Humphreys & Forde, 1998). For example, Kessler et al. (2007) showed that, relative to people with mild to moderate dementia, people with schizophrenia committed a significantly smaller proportion (in relation to all errors) of omissions (e.g., failures in completing task steps), but a significantly greater proportion of perseverations and off-task behaviors in the completion of everyday tasks (i.e., commission errors). Relative to other executive functions, mental control and manipulation have been most strongly associated with errors on performance-based measures of everyday actions in people with schizophrenia (Kessler et al., 2007; Vaughan & Giovanello, 2010). Mental control and manipulation deficits also have been associated with high rates of commission errors (but not omission errors) in people with dementia (Giovannetti et al., 2008). The extent to which patients with schizophrenia demonstrate a homogeneous pattern of everyday action deficits is unknown, although individuals with especially poor performance on tests of executive control and manipulation might be most vulnerable to functional impairment. Our central hypothesis is that people with schizophrenia vary with respect to their functional ability and that this variability will be associated with differential executive deficit patterns.

The present study evaluated this hypothesis using a person-centered approach. In contrast to variable-centered approaches (e.g., regression, analysis of variance), person-centered approaches offer the opportunity to examine *patterns* of executive function abilities *within* individuals (Bates, 2000; Muthén & Muthén, 2000). Person-centered approaches, including latent class analysis (LCA), are especially useful when data include heterogeneous groups of individuals because they are able to group individuals into classes that contain individuals who are similar in terms of different dimensions (e.g., ability to maintain mental set vs. inhibition), performance within dimension (e.g., high vs. low inhibition), or both (Muthén & Muthén, 2000; Nylund, Asparouhov, & Muthén, 2007; Nylund, Bellmore, Nishina, & Graham, 2007). LCA was used for the present study because of its advantages over cluster analysis, including the model based, probabilistic approach that permits replication with other samples; statistical fit indices for determining model fit and number of classes; and the ability to generate reliable classes using predictor and outcome variables drawn from different types of scales and with different variances (DiStefano & Kamphaus, 2006; Magidson & Vermunt, 2002; Nylund, Asparouhov, et al., 2007; Nylund, Bellmore, et al., 2007).

Within the framework of a novel person-centered approach, an effort was made to select executive functioning constructs and representative variables that were clinically relevant and consistent with existing empirical models. As detailed above, there is a lack of consensus across studies regarding the nature of specific executive components. Therefore, we drew from several prior studies to construct the theoretical model of the current investigation. This rationale is explained in greater detail in the Method section.

In summary, the first aim of the current study was to empirically define and characterize schizophrenia participant groups with a person-centered analytic approach using indices of various executive function abilities. We hypothesized that participants would group into distinct executive function classes that would differ in terms of executive function dimensions (qualitatively) and performance within dimensions (quantitatively). The second aim was to test the construct and predictive validity of the classes identified in the first aim by comparing the empirically defined classes on errors committed during the performance of everyday tasks. We hypothesized that classes would demonstrate different functional patterns on tasks of everyday actions.

METHOD

Participants

All participants (N=45) were recruited from the inpatient psychiatric units of two local hospitals in Philadelphia. All individuals met *Diagnostic and Statistical Manual of Mental Disorders–Fourth Edition, Text Revision* (*DSM–IV–TR;* American Psychiatric Association, 2000) criteria for schizophrenia or schizoaffective disorder. All participants were English speaking and taking at least one antipsychotic medication. Participants were chronically ill, from urban neighborhoods in Philadelphia, and met the following inclusion criteria: (a) no history of traumatic brain injury or neurological disorder, such as cerebral vascular accident or epilepsy; (b) no alcohol or illicit substance use within one month prior to study participation; and (c) no mental retardation as determined by performance on the Kaufman Brief Intelligence Test–Second Edition (KBIT 2; Kaufman & Kaufman, 2004). On average, participants were 43.36 years old (*SD*=10.87) with 11.89 years of education (*SD*=2.23). Approximately half of the sample was composed of women (*n*=22; 49%).

Materials and procedure

Data for this study were compiled from participants who took part in a previously published study (Kessler et al., 2007; *n*=23) and from participants whose data were collected after the study's publication (*n*=22). All participants were recruited from a larger study that examined the influence of environmental adaptations on everyday action performance (Kessler, 2010). Data collection and procedures were approved by the Institutional Review Board of Temple University, and all participants signed an approved consent form and were paid for their efforts. To minimize fatigue, participants completed all measures within two to three 2-hour sessions over the course of one month. Before every testing session, participants were determined to be stable relative to their baselines, and they were not assessed on days when "as needed" medications were administered.

Measures

Executive function—As part of a previous study (Kessler, 2010), participants were administered various subtests from the D-KEFS (Delis et al., 2001), the Behavioural Assessment of the Dysexecutive Syndrome (BADS; Wilson, Alderman, Burgess, Emslie, & Evans, 1996), and the Wechsler Adult Intelligence Scale–Third Edition (WAIS–III; Wechsler, 1997) to assess executive function processes. The current study used the raw scores of specific subtests to represent three executive function constructs. Raw scores were used to maximize the range of scores and optimize the statistical procedures used in this study (described below). Two variables were chosen to represent each executive construct, resulting in a total of six executive function variables. This was done in an effort to accurately capture the construct through multiple measures while maintaining a sufficient number of participants per variable. These variables and their targeted executive functions are described below and are summarized in Table 1.

The executive constructs targeted in the present study were selected based on our review of the literature on executive components in healthy controls and people with schizophrenia. We were largely influenced by the model proposed in the benchmark study of healthy participants by Miyake and colleagues (2000), but we modified this model in light of the schizophrenia literature (Barch & Smith, 2008; Savla et al., 2011), as investigators have illustrated the difficulties of generalizing models developed with healthy participants to clinical populations (Delis, Jacobson, Bondi, Hamilton, & Salmon, 2003). We also were motivated to include constructs assessed by widely used clinical measures in an attempt to enhance the clinical utility of our results. Thus, we chose three executive constructs—ability to maintain mental set, mental control/manipulation, and inhibition.

Ability to maintain mental set—The ability to maintain mental set construct was selected in place of Miyake and colleagues' (2000) shifting construct, because recent findings by Savla et al. (2011) suggest that the difficulties commonly experienced by patients with schizophrenia on tasks of switching at least partially reflect impairment in the more basic skills required to complete these tasks. We reasoned that individuals must achieve the more basic ability of maintaining one or more mental sets or goals to be able to successfully shift, or switch, between mental sets (Lamar, Price, Davis, Kaplan, & Libon, 2002). In fact, the ability to maintain mental set, or goal maintenance, has been identified as a core executive deficit in schizophrenia (Barch & Smith, 2008).

Two measures were used to evaluate ability to maintain mental set: total correct raw score responses in letter fluency (FAS total), and the combined total of set-loss errors summed across all conditions of verbal fluency (FAS, Animals, Boys' Names, and Switching) plus errors committed on the number–letter switching condition of the Trail Making Test (set-loss errors).

Mental control/manipulation—The mental control/manipulation construct closely resembles the updating/monitoring construct of Miyake et al. (2000), as we define this construct as the active and dynamic manipulation of information in working memory. To measure this construct, the raw score time to completion of the number–letter switching condition of the Trail Making Test (Trails Switching) and the total number of correct trials of Digit Span Backwards (Digit Span Backwards) were used. Although these tests are superficially quite different, each requires the manipulation of information in working memory (Sanchez-Cubillo et al., 2009).

Inhibition—Several investigators define the executive function of inhibition as an individual's ability to inhibit a prepotent response (Delis et al., 2001; Miyake et al., 2000). To assess this construct, we used the raw score time to completion on the Color–Word Interference Test (Color–Word Interference). The Color–Word Interference Test is akin to the classic Stroop test that requires one to inhibit the prepotent reading response to a word stimulus. The total number of perseverative responses produced during all conditions of verbal fluency was used as the second measure of inhibition (total perseverations). This measure is based on the work of Hedden and Yoon (2006), which has suggested that inhibition may encompass the differential underlying ability to overcome proactive interference from previously produced items.

Although some authors suggest that verbal fluency is generally a measure of one's ability to overcome proactive interference from previously produced items (Gurd & Oliveira, 1996), others have proposed that perseverative responding reflects a failure to inhibit a highly activated and prepotent response (Leimkuhler & Mesulam, 1985). Given these conflicting theoretical viewpoints, we thought it important to include perseverative responding in tasks of verbal fluency as a measure of inhibition to better capture this construct.

Everyday action—Participants completed the Naturalistic Action Test (NAT; Schwartz, Buxbaum, Ferraro, Veramonti, & Segal, 2003; Schwartz, Segal, Veramonti, Ferrara, & Buxbaum, 2002), a performance-based measure of everyday task performance that has been validated, standardized, and found to have good psychometric properties (Schwartz et al., 2002). The NAT manual (Schwartz et al., 2003) provides detailed and standardized set-up procedures, administration and scoring instructions, and normative data. The NAT examines overall task performance, successful task completion, and a range of specific error types of participants as they complete three independent trials of everyday tasks. These everyday task trials include (a) preparing a slice of toast with butter and jelly and preparing a cup of coffee with cream and sugar; (b) wrapping a gift while ignoring related distractor objects; and (c) packing a lunchbox including a sandwich, a snack, and a drink, and packing a schoolbag with school supplies after locating several necessary items that are out of view in a drawer and ignoring several potentially distracting objects also contained in the drawer.

NAT performance was videotaped for all participants, and performance was carefully scored according to the NAT manual. This scoring procedure has consistently yielded excellent interrater reliability for both accomplishment scores and overall error rates (Kessler, 2010; Schwartz et al., 2002; Schwartz et al., 2003). In the present study, NAT total errors were examined, as well as two major NAT error categories: omissions and commissions. Omission errors are committed when an individual fails to perform a task step or subtask (e.g., failure to add sugar to the coffee). Commission errors encompass errors of inaccurate task execution and include the specific error types of perseverations and action additions. Past studies have shown that errors of commission are associated with executive measures of mental control/manipulation (Giovannetti et al., 2008; Kessler et al., 2007). Perseveration errors are coded when a task or subtask is performed more than once, or an action is performed repetitively or for an excessive amount of time (e.g., toasting multiple pieces of bread, using excessive amounts of tape while wrapping the present). Action addition errors are defined as actions that are not readily interpreted as a task step (e.g., playing with the doll before wrapping it as a gift). Perseverations and action additions were analyzed separately, because they have uniquely characterized the everyday task performance of patients with schizophrenia in comparison to other clinical populations, including brain injury, right and left hemisphere stroke, and dementia (Kessler et al., 2007).

Statistical analyses

Raw scores for all neuropsychological and NAT variables used in the present study are presented in Table 2. All statistical analyses were performed with Mplus Version 5.2 (Muthén & Muthén, 1998–2007). LCA was used first to empirically identify schizophrenia groups based on the six previously described variables of executive function. Given that LCA allows for the use of nonstandardized variables (Nylund, Asparouhov, et al., 2007; Nylund, Bellmore, et al., 2007), raw scores were used to maximize the variability in scores. Unlike other person-centered techniques such as cluster analysis, which is "structure seeking" and identifies the number of classes requested by a researcher, LCA uses a stepwise procedure and a variety of fit indices to determine whether the addition of classes improves the fit to the data (Beauchaine, 2003). Thus, there are no "gold standard" guidelines regarding the number of participants and power for a proposed LCA. Instead, a variety of statistical indices and conceptual considerations are taken into account to determine which model fits the data best (Nylund, Asparouhov, et al., 2007; Nylund, Bellmore, et al., 2007). LCA models are fit in a series of steps, starting with a one-class (independence) model. The number of classes then is increased one class at a time until there is no additional improvement to the fit of the model (Nylund, Asparouhov, et al., 2007; Nylund, Bellmore, et al., 2007).

Various statistical fit indices were examined to determine the best fitting model. These indices include the Akaike information criterion (AIC; Akaike, 1987), Bayesian information criterion (BIC; Schwartz, 1978), and adjusted BIC (ABIC; Sclove, 1987). The model that yields the smallest values on these indices is considered the best fitting model. Additionally, we considered the Bootstrap Likelihood Ratio Test (BLRT), which compares the model with k classes to the model with $k-1$ classes; the resulting p-value indicates whether model fit significantly improves from the model that includes $k-1$ versus k classes (Nylund, Asparouhov, et al., 2007; Nylund, Bellmore, et al., 2007). In addition, conceptual model and theory influence model selection. Specifically, models are examined to determine whether the addition of another class is substantively and clinically meaningful and consistent with previous research and the researchers' conceptual model. Last, the smallest class size is considered. Classes composed of less than 10% of the total sample suggest overfitting of the data and that the classes may be difficult to replicate. Monte Carlo simulation studies using a variety of sample sizes suggest that the BIC and BLRT are the most robust indicators of classes. If the study were underpowered to perform these analyses or a one-class model provided the best fit to the data (suggesting that a person-centered approach is not necessary), fit statistics would converge to suggest that the one-class (unconditional) model should be selected.

LCA models were run with and without age and education[1] variables to determine whether these demographic variables influenced class membership. Following identification of classes, tests of equality of means across latent classes were conducted to determine whether classes differed in terms of demographic variables and everyday action errors (i.e., total NAT errors, omission errors, commission errors, perseverations, and action additions). The test of equality of means holds class membership constant and provides chi-square statistics for omnibus and pairwise comparisons across latent classes. Pairwise comparisons were examined only if the omnibus tests were significant. All analyses were determined to be significant when p <.05.

RESULTS

Latent class analysis

LCA models were conducted with the scores of the six neuropsychological variables reflecting various executive functions (see Table 2). The one-class model was fit first, followed by models with two and three classes. Examination of Table 3 indicates that the lowest BIC, AIC, and ABIC were found for the three-class model; moreover, the BLRT indicated that the three-class model provided an improvement in fit from the two-class model. The four-class model would not converge owing to local maxima (i.e., potentially extreme scores). However, in addition to the fit indices supporting adoption of the three-class model, some of the class sizes (n=5, 9, 31) were relatively small, and thus further division of these classes might not have been substantively meaningful. We repeated these analyses with increased starting values and obtained the same three-class solution each time. We also re-ran the LCA models including age and education along with the EF tests. The addition of age and education did not influence the number of latent classes, or the distribution of individuals within those classes.

Conceptual considerations and our theoretical framework were used to characterize the three-class model. Mean raw and norm-based z scores for the executive function variables across the three classes are included in Table 4. Class 1 (multiple EF deficits; n=5) was characterized by marked impairment in executive function relative to the other classes. Individuals in Class 1 obtained the lowest scores on both variables reflecting the ability to maintain mental set (FAS total and set-loss errors), one test of inhibition (Color–Word Interference), and one test of mental control/manipulation (Digit Span Backwards). However, performance on the second test of mental control/manipulation (Trails Switching) was significantly impaired but comparable to that of Class 3; the second measure of inhibition (total perseverations) was relatively low, reflecting good performance. Individuals in Class 2 (spared EF; n=9) demonstrated relatively spared executive functions when their performance was compared to that of the individuals in the other two classes. Class 3 (perseverative; n=31) was distinct in terms of the high number of total perseverations on verbal fluency, with twice as many perseverative responses as the other classes. As stated previously, Class 3 also performed poorly and comparably to Class 1 on Trails Switching.

Age and education analyses

Omnibus between-group analyses revealed that classes differed significantly in age (Table 5). Follow-up pairwise comparisons revealed that Class 2 (spared EF) was significantly younger than both Class 1 [multiple EF deficits; $\chi^2(1)=9.82$, $p< .01$] and Class 3 [perseverative; $\chi^2(1)=5.60$, $p=.02$]. As stated earlier, when age was included with the EF variables in the LCA, the class structure did not change. This stability indicates that although age differed across the classes, it did not influence class membership beyond the EF variables. Education did not significantly differ across the three classes.

[1]For this analysis, education was divided into the following three categories: 0–11 years, 12 years, and 13 years or higher.

Comparisons of NAT variables among classes

Omnibus between-group analyses comparing NAT errors across the three classes showed significant differences for total errors, commissions, and perseverations (Table 5). The three classes did not significantly differ on omissions or action additions.

Follow-up pairwise comparisons revealed no differences between Class 1 (multiple EF deficits) and Class 3 (perseverative) on any of the error categories, $\chi^2(2)$s < 2.52, *p*s>.11, φs < .28 for all. Relative to Class 2 (spared EF), however, Class 3 (perseverative) committed significantly more total errors, $\chi^2(1)=7.55$, $p < .01$, $\varphi=.43$, commissions, $\chi^2(1)=4.90$, $p=.03$, $\varphi=.35$, and perseverations, $\chi^2(1)=6.75$, $p < .01$, $\varphi=.41$. Individuals in Class 1 (multiple EF deficits) had significantly more perseverative errors in everyday action than Class 2 (spared EF), $\chi^2(1)=7.54$, $p < .01$, $\varphi=.73$, and they showed trend-level differences between Class 2 (spared EF) on total errors, $\chi^2(1)=3.27$, $p=.07$, $\varphi=.48$, and commissions, $\chi^2(1)=3.26$, $p=.07$, $\varphi=.48$. Although power was sufficient to identify three classes among this sample, comparisons between Classes 1 and 2 may not have reached significance because of the small class sizes ($n=5$ and 9), despite the large magnitude of the effect sizes (both $\varphi=.48$).

DISCUSSION

The first aim of the present study was to empirically define and characterize schizophrenia patient groups based on various executive function abilities to discern whether individuals differed in severity and/or type of executive function impairment. Results demonstrated that the executive function performance of people with schizophrenia is, in fact, qualitatively heterogeneous in nature. The second aim was to evaluate whether everyday action abilities meaningfully differed among schizophrenia participants with different patterns of executive impairment. The findings revealed that participants with relatively spared executive functioning also showed spared everyday action performance, but participants with different patterns of executive impairment did not differ in their ability to perform everyday tasks.

LCA model fit indices revealed that a three-class model best fit participants' executive function data. Unlike previous studies that classified executive dysfunction severity by the number of impaired executive measures (Chan, Chen, Cheung, et al., 2006; Chan, Chen, & Law, 2006), LCA allowed identification of descriptive patterns of executive function performance. The three resulting classes were best characterized by relatively spared executive abilities, multiple executive deficits, and perseverative responding. These results suggest that individuals with schizophrenia should not be characterized *only* by severity of executive impairment or by the number of measures on which an individual demonstrated impaired performance (Chan, Chen, Cheung, et al., 2006). The LCA results revealed that this ordering of symptom severity might not, in fact, be the most accurate characterization of patient deficits. Instead, the three-class model provides evidence that executive function performance among persons with schizophrenia is qualitatively heterogeneous and can be characterized by specific patterns of performance (i.e., relatively spared executive functioning, perseverative responding, multiple executive function deficits). This underscores the importance of assessing specific executive abilities when characterizing the cognitive strengths and weaknesses of individuals with schizophrenia.

Our findings support previous work showing that dissociable constructs comprise executive functions (Hedden & Yoon, 2006; Hull et al., 2008; Miyake et al., 2000). The specific patterns of executive deficits across the classes were not consistent with prior work conducted with healthy young adults and older adults using variable-centered approaches (see Delis et al., 2003). The findings also were not entirely consistent with past studies examining discrete executive components in schizophrenia (Barch & Smith, 2008; Chan et al., 2004; Clark et al., 2010; Savla et al., 2011). Our resultant classes suggested that groups were not defined by their performance on our inhibition construct (i.e., performance on both Color–Word Interference and total perseverations) or our mental control/manipulation construct (i.e., performance on both Trails Switching and Digit Span Backwards). It is possible that the constructs we chose are multifactorial. For example, some authors have proposed that the construct of inhibition may be best understood as a multidimensional executive construct that captures both inhibition of a prepotent response (Color Word Interference) and the ability to overcome proactive interference (total perseverations; Hedden & Yoon, 2006; Hull et al., 2008). Differences in study populations, executive measures, and statistical approaches might also explain the variability across studies.

Our results revealed that perseverative responding on various conditions of verbal fluency most distinctly differentiated the classes with executive impairment (Class 1 and Class 3). This finding is unique, as this is the first study to our knowledge to characterize patients with schizophrenia according to specific patterns of executive deficits. Perseverative responding on tasks of verbal fluency may reflect a relatively circumscribed executive function deficit. The findings suggest that patients who are particularly perseverative are qualitatively different than patients with multiple executive function deficits or relatively intact executive functioning. Interestingly, participants who were perseverative (Class 3) performed comparably to participants with relatively spared executive functions (Class 2) on verbal fluency total correct output. This heterogeneity in functioning *within* and *between* classes reinforces that executive function deficits in patients with schizophrenia are likely not ordered by severity. Additional research is needed to replicate these findings. Until then, the variability in specific executive components across studies precludes firm conclusions regarding the architecture of executive functions.

The second aim of the present study was to compare these empirically defined executive function performance classes on errors committed during the performance of everyday actions to determine whether individuals with specific patterns of executive deficits differ in everyday action performance. These comparisons allowed for the assessment of the ecological and predictive validity of these classes. Analyses revealed that classes were associated with different degrees of functional deficits on tasks of everyday action. Specifically, individuals classified by their perseverative responding on executive function tasks committed a significantly greater number of total errors, commissions, and perseverations on tasks of everyday action than did individuals with relatively spared executive functioning. Interestingly, the perseverative group did not differ from the group characterized by multiple executive function deficits on number of total errors, commission errors, or perseveration errors. Both classes with executive impairment (multiple EF deficits and perseverative) showed comparably high rates of errors on everyday tasks. Furthermore, the action errors made by both classes with executive deficits may be characterized as commissions and, more specifically, perseverations. Thus, deficits that differentiated the executive classes (multiple EF deficits vs. perseverative responding on verbal fluency) may not meaningfully influence different patterns of everyday difficulties in this population. In other words, any form of executive dysfunction, whether pervasive or distinct in terms of frequent perseverative responding, is associated with marked everyday action impairment among people with schizophrenia.

Interestingly, although qualitatively and distinctly different in their patterns of perseverative responding, individuals in Class 1 (multiple EF deficits) and Class 3 (perseverative) demonstrated nearly identical severely impaired performance on one executive function variable chosen to assess mental control/manipulation (i.e., Trails Switching). In this regard, the present study adds to the current literature (Kessler et al., 2007; Vaughan & Giovanello, 2010), supporting a strong association between impairment in mental control/manipulation and functional deficits in schizophrenia. It also supports findings showing an association

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between mental control/manipulation and everyday errors of commission in people with dementia (Giovannetti et al., 2006, 2008). Performance on Digit Span Backward, which also was selected to evaluate mental control/manipulation, patterned differently than Trails Switching across the classes, suggesting that visually mediated mental control/manipulation or processes associated with alternating attention or task switching may be particularly important for everyday action performance.

The results of the present study additionally suggest that individuals with schizophrenia and relatively spared executive functions demonstrate significantly better performance of everyday tasks than do individuals with schizophrenia and executive deficits. However, compared to published normative data on the NAT, even participants with schizophrenia and relatively spared executive functions (Class 2) showed functional deficits, with error rates approximately three times higher than the error rate observed in healthy participants (normal control *M* comprehensive error score=2.18; *SD*=1.83; Kessler et al., 2007).

It is important to note that the class demonstrating relatively spared executive functioning was significantly younger than the other two classes. Executive functioning deficits may be exacerbated among older individuals because of age-related effects on cognition or their illness, or as a consequence of prolonged treatment (e.g., medications, institutionalization; Fucetola et al., 2000). However, age also may be a proxy for other disease variables, which should be examined more closely in future longitudinal research and replication studies. It is important to reiterate that the inclusion of age into the LCA as a model variable did *not* influence the number of classes or the distribution of individuals within those classes, which suggests that executive function performance, but not age, was a distinguishing factor in determining class membership.

A limitation of the present study is that the sample size and resulting latent classes were relatively small and may have led to nonsignificant results in pairwise class comparisons of everyday action performance. Increased sample size, and consequently subsample sizes, could have resulted in further characterization of action deficits among the three identified executive function classes. Nevertheless, the classes identified were consistent with theory, substantively meaningful, differentiated on executive function performance, and predictive of everyday action performance, indicating that the sample size was large enough for the aims of the present study. We acknowledge that there is considerable debate regarding the mapping between clinical executive measures and underlying executive constructs, and some might have selected different executive measures. It remains possible, as does much work with executive function variables, that the measures chosen to represent our executive function constructs of interest did not optimally or purely capture target constructs. However, the measures were chosen based on theory and previous research, and the chosen variables are commonly used in clinical evaluations of individuals with schizophrenia.

To our knowledge, the present study is the first to use the person-centered statistical approach of latent class analysis to characterize patterns of executive function performance among individuals with schizophrenia. Additionally, the present study utilized performance-based action measures to characterize everyday functioning in patients with schizophrenia, increasing the ecological validity of our findings and demonstrating the predictive validity of the identified classes. Through this novel methodology, the LCA yielded three meaningful patient groups that differed in terms of real-world deficits. Notably, these groups were identified in a sample of chronically ill inpatients; further research is needed to determine whether the findings generalize to individuals with schizophrenia living independently in a recovered phase of illness.

In conclusion, the present study suggests that individuals with chronic schizophrenia demonstrate qualitatively different patterns of executive deficits that contribute to functional deficits, with impaired switching abilities associated with marked deficits in everyday action. Further investigation is necessary to better understand the influence of different executive function deficit patterns on everyday functioning and other types of adaptive functioning, as it is possible that individuals with different executive deficits might show differential performance patterns on aspects of everyday functioning not assessed in the present study. Additional research with other types of functional assessments (e.g., social functioning, everyday error monitoring) and evaluations of symptom profiles and symptom severity (see Clark et al., 2010) are needed. Investigators have shown an association between perseverative responding and poor insight among people with schizophrenia (Lysaker, Bell, Bryson, & Kaplan, 1998). Thus, individuals with high rates of perseveration might show a unique pattern of functional deficit characterized by deficient error detection or limited awareness. Individuals with different executive deficit patterns also may respond differently to interventions designed to improve functional independence, and investigators should consider patients' specific executive deficit patterns when making treatment decisions. Although these open questions remain for future study, our results suggest that clinicians should employ interventions that target task mental control and manipulation deficits in order to improve functional outcomes for people with chronic schizophrenia.

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Table 1

Neuropsychological variables of executive functions

Targeted executive function	Test(s)	Dependent variable	Variable name
Ability to maintain mental set	D-KEFS Verbal Fluency Test, letter fluency (FAS) condition	Total correct responses	FAS total
Ability to maintain mental set	D-KEFS Verbal Fluency Test, all conditions; Trail Making Test, number–letter switching condition	Total set-loss errors, summed across all fluency conditions and switching condition of Trail Making Test	Set-loss errors
Mental control/manipulation	D-KEFS Trail Making Test, number–letter switching condition	Time to completion (seconds)	Trails Switching
Mental control/manipulation	WAIS–III Digit Span, Backwards condition	Total correct trials	Digit Span Backwards
Inhibition	D-KEFS Color–Word Interference Test, Interference condition	Time to completion (seconds)	Color–Word Interference
Inhibition	D-KEFS Verbal Fluency Test, all conditions	Total perseverations, summed across all fluency conditions	Total perseverations

D-KEFS = Delis–Kaplan Executive Function System; WAIS–III = Wechsler Adult Intelligence Scale–Third Edition.

Table 2

Neuropsychological and naturalistic action test raw score data

	M	*SD*	Range
Neuropsychological test scores			
Ability to maintain mental set			
FAS total	24.11	10.17	6–50
Set-loss errors	6.37	4.87	0–22
Mental control/manipulation			
Trails Switching condition	208.07	54.06	70–240
Digit Span Backwards	4.07	1.66	1–8
Inhibition			
Color–Word Interference	94.60	36.98	44–180
Total perseverations	3.31	5.18	0–31
NAT performance variable scores			
Total errors	11.59	8.59	2–42
Total omission errors	2.00	2.33	0–9
Total commission errors	9.38	8.16	0–41
Total perseveration errors	2.34	2.62	0–9
Total action addition errors	1.82	3.62	0–20

NAT = Naturalistic Action Test. $n = 45$.

Table 3

Fit indices for latent class analysis models with 1–3 classes

Number of classes	Number of free parameters	Log likelihood	AIC	BIC	ABIC	BLRT
1	12	−943.247	1,910.494	1,932.174	1,894.559	N/A
2	19	−907.434	1,852.869	1,887.195	1,827.638	0
3	26	−890.434	1,832.867[a]	1,879.841[a]	1,798.342[a]	0

AIC = Akaike information criterion; BIC = Bayesian information criterion; ABIC = adjusted BIC; BLRT = Bootstrap Likelihood Ratio Test. A four-class model would not converge with the data and is consequently not reported.

[a] Indicates best fitting model according to that index.

Table 4

Neuropsychological test scores across three-class model

	Latent Class 1 Multiple EF deficits (n = 5)				Latent Class 2 Relatively spared EF (n = 9)				Latent Class 3 Perseverative (n = 31)			
	Raw score		Norm-derived *z* score		Raw score		Norm-derived *z* score		Raw score		Norm-derived *z* score	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Ability to maintain mental set												
FAS total	16.14	5.57	−2.27	0.43	24.62	10.14	−1.29	1.09	25.38	10.3	−1.24	0.96
Set-loss errors	10.62	9.19	N/A[a]	N/A[a]	3.00	2.67	N/A[a]	N/A[a]	6.64	4.12	N/A[a]	N/A[a]
Mental control/manipulation												
Trails Switching	238.72	8.83	−3.00	0	109.59	22.95	−1.11	1.00	233.29	16.87	−3.00	0
Digit Span Backward[b]	2.87	1.03	−1.42	0.20	5.07	1.74	−0.62	0.73	3.98	1.61	−1.06	0.66
Inhibition												
Color–Word Interference	175.92	15.36	−3.00	0	72.13	17.82	−1.48	1.49	86.85	27.61	−1.90	1.23
Total perseverations	1.53	1.72	0.27	0.60	1.47	2.04	0.19	0.79	3.27	3.51	−0.45	1.11

EF = executive function.

[a]Normative data were not available as this variable was derived from multiple scores across different tests.

[b]Raw score data reflect total correct digits backward; normative data were calculated for longest digits backward span due to limited availability of normative data.

Table 5

Comparisons of naturalistic action test performance variables between latent classes

	Class 1		Class 2		Class 3					
	Multiple EF deficits		Relatively spared EF		Perseverative					
	(*n* = 5)		(*n* = 9)		(*n* = 31)		Omnibus chi-square test			
Demographic variables	***M***	***SD***	***M***	***SD***	***M***	***SD***	χ^2,[b]	***p***	***φ***	**Pairwise comparisons**
Age (years)[a]	49.88	6.62	34.95	11.18	44.73	9.83	9.93	.01		2 < (1, 3)
Education (years)	11.60	2.07	12.11	2.76	11.87	2.16	0.77	.68		–
NAT performance variables										
Total errors[a]	17.55	12.82	6.98	3.27	11.96	8.02	8.81	.01	.44	3 > 2
Total omission errors	1.08	1.32	1.22	1.23	2.40	2.67	3.07	.22	.26	–
Total commission errors[a]	16.47	13.07	5.76	2.67	9.25	7.24	6.80	.03	.39	3 > 2
Total perseveration errors[a]	4.62	2.94	0.89	0.99	2.39	2.62	12.61	<.01	.53	(3, 1) > 2
Total action addition errors	4.85	7.29	0.45	0.96	1.70	2.67	5.59	.06	.35	–

EF = executive function; NAT = Naturalistic Action Test. The reported chi-square analysis for education was conducted with education divided into three categories: 0–11 years, 12 years, 13 years or higher. Means and standard deviations were reported in years.

[a]Indicates statistically significant differences across three classes.

[b]d*f* = 2.