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Research Paper

Linguistic and neurocognitive correlates of probabilistic classification learning in schizophrenia

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ABSTRACT

Individuals with schizophrenia demonstrate impaired implicit learning on cognitively complex tasks and preserved implicit motor learning. However, little is known about how implicit learning may be related to other linguistic and cognitive variables, including development of complex language including comprehension and syntax. This study explored the relationship between probabilistic classification learning, a type of implicit learning style, and linguistic and cognitive skills in schizophrenia. This was done by examining how schizophrenia patients perform on the Weather Prediction Task (WPT) relative to controls, particularly during a dual-task interference condition that assesses task automaticity. Individuals with schizophrenia ($N = 34$) demonstrated depressed cognitive functioning relative to the controls ($N = 18$) across nearly all cognitive functions. On the Weather Prediction Task, the schizophrenia group performed less accurately than the control group in later blocks and had a relatively flat learning curve. A significant Group X Block effect when controlling for age and sex suggested differential learning throughout the task. A subgroup of patients did not develop automaticity during the repeated blocks of trials. For those patients who did not develop automaticity over the course of the WPT, linguistic and cognitive skills were strongly correlated with their Block 1 performance. For patients who developed automaticity, overall neurocognitive ability was correlated with their ultimate level of performance on the WPT but not with their Block 1 performance. That language was related to differential learning emphasizes the role of explicit, verbal processes on making initial rapid improvement on the WPT.

1. Introduction

Understanding the nature of implicit learning in patients with schizophrenia may be important for understanding the development of disorganized speech and other cognitive deficits that affect communication in schizophrenia. The connection between implicit learning and thought disorder/disorganized speech is important because speech patterns are learned implicitly as the language production system adapts to recent experience (Dell et al., 2000). These language deficits may, in part, reflect a neurodevelopmental etiology involving a disturbance in processing rapid, sequential information present in speech (Condray, 2005). Early deficits in implicit learning may represent a common pathway for the development of cognitive and language deficits observed in schizophrenia patients and their relationship to implicit learning may help identify important targets for early intervention in prodromal youth. It may also help us understand why some individuals with schizophrenia have difficulty responding to traditional forms of therapy that may rely on insight and generalization of concepts. Separating responders from non-responders, if related to implicit and/or probabilistic learning, would allow researchers to refine intervention strategies and provide more targeted care.

While there are some studies that indicate that implicit learning may be intact in schizophrenia patients, a growing body of evidence suggests that implicit learning in schizophrenia patients is reduced when accuracy and dual-task interference are considered (Danion et al., 2001; Siegert et al., 2008; Chiu et al., 2005). However, few studies have looked at the relation between dual-task performance and neuropsychological measures of working memory (Wagshal et al., 2012). Likewise, few

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studies have looked at individual differences within the schizophrenia patients, which could help explain variable results in the literature.

1.1. Implicit learning

In a meta-analysis, Siegert et al. (2008) find evidence for impaired implicit learning in schizophrenia patients across nine different studies. In all nine of the studies, schizophrenia patients perform worse on a serial reaction time task (SRTT), an implicit motor learning task. The pooled estimate of effect size is moderate (0.51). However, Foerde et al. (2008) reports no meaningful difference in learning performance on the serial reaction task between schizophrenia patients and control subjects. While the control group demonstrates statistically significant greater accuracy on the task, both the participants in the control group and those with schizophrenia have high accuracy scores averaged across all blocks (97.9% vs 94.5%).

Tasks involving higher order cognitive skills demonstrate more significant impairments among participants with schizophrenia. Performance on the Weather Prediction Task (WPT), a probabilistic classification task (Foerde et al., 2008; Gomar et al., 2011) is impaired in patients with schizophrenia (Foerde et al., 2008; Horan et al., 2008; Keri et al., 2005; Weickert et al., 2002) and their adult and adolescent relatives (Wagshal et al., 2012; Wagshal et al., 2014; Weickert et al., 2010). In Forde et al., in contrast to their performance on the SRTT the schizophrenia group demonstrates few improvements across three extensive sessions, whereas the control group makes rapid gains in the first session of training, reaching asymptote in subsequent sessions (Foerde et al., 2008). The significant difference between accuracy on the SRTT and WPT suggests that implicit learning is not a unified process and neurocognitive variables affected by either the disease process or genetic liability for the disorder can adversely affect an individual's ability to learn from complex feedback.

In contrast, Kéri et al. (2000) finds that schizophrenia patients show preserved accuracy on the probabilistic classification task. However, when asked to explicitly state their recall memory for the cues, what they predicted and how often, the schizophrenia patients are unable to recall and/or elaborate on their strategy. This effect was especially pronounced for cue combinations of 2 or 3 cards (Kéri et al., 2000). This body of research suggests that when implicit learning is intact in schizophrenia patients, they are able to learn and develop new skills as much as controls, despite having limited episodic memory for the acquired skill or information.

Others suggest that while individuals with schizophrenia demonstrate decreased accuracy relative to controls, the learning rate across trials is similar for both groups (Weickert et al., 2002) reflecting persistent differences at baseline.

1.2. Correlates of deficit

Some have suggested that rather than difficulties with implicit learning, global cognitive impairment can explain poor WPT performance. When matched for IQ (within 5 points), the impaired probabilistic classification task performance appears to diminish, as accuracy on early trials of the task are no longer significantly different (Gomar et al., 2011). Because IQ is a gross measurement of cognitive function comprised of several subtests measuring several aspects of verbal reasoning, nonverbal reasoning, working memory, and processing speed, it is important to distinguish which cognitive skills most likely contribute to the observed implicit learning deficit.

Some believe that healthy controls often use a variety of strategies that require some form of cue combination or other highly-organized strategies to perform the WPT that schizophrenia patients do not used because of disorganized thinking, which is a characteristic feature of schizophrenia (Chiu et al., 2005). This theory is consistent with findings that schizophrenia affects a corticostriatal circuit (Foerde et al., 2008), as this network includes significant frontal lobe connectivity that mediates executive functioning. The probabilistic classification task may be unique in that the cognitive functioning required by this task is a unique combination of working memory, long-term memory, motor responses, and memory recall, recognition and consolidation. That is, the task involves implicit and explicit strategies to remember the cue card associations they have learned, examine which outcome is likely to occur, understand and integrate the feedback given the current understanding, move their hand to execute the decision making process, and understand that the feedback itself is probabilistic. The intersection of all these processes makes it difficult to attribute deficits on the probabilistic classification task to implicit memory, without further understanding the various cognitive skills related to the task.

1.3. Effects of medication use

Antipsychotic use has also been found to influence performance on implicit learning due to extrapyramidal side effects (Granholm et al., 1993; Purdon et al., 2003). Specifically, individuals with tardive dyskinesia, a potential side effect of many neuroleptic medications, perform more poorly than controls on an implicit motor learning tasks (e.g., the pursuit rotor task) (Granholm et al., 1993). In some instances, the impact of antipsychotic use is related to duration of treatment and/or length of illness variables; these studies found no effects on motor learning using the Tower of Toronto test within 6 weeks of treatment and significant declines after 6 months of antipsychotic use (Purdon et al., 2003). However, other studies fail to find similar results (Kéri et al., 2000; Gomar et al., 2011; Foerde et al., 2008). Specifically, schizophrenia patients with Parkinsonism and tardive dyskinesia demonstrate worse accuracy than controls but similar learning curves across implicit learning tasks including the WPT (Gomar et al., 2011; Foerde et al., 2008). Second-generation antipsychotics have lower incidence of these side effects, so their impact on implicit learning is less well known.

1.4. Potential genetic contributions to implicit memory function

Unaffected relatives of AOS and COS patients also show deficits on WPT indicating that the deficits found in patients are not simply due to presence of cognitive deficits reflecting psychotic symptoms or the effects of antipsychotic medications. There may be familial transmission of impairment of processes that are required for successful performance on the WPT (Wagshal et al., 2012; Wagshal et al., 2014).

1.5. Aims and hypotheses

This study sought to examine the performance of schizophrenia patients and typically developing individuals on the WPT and the relationship between this performance and performance on measures of language and cognitive functioning. Because of the impact of schizophrenia on early neurocognitive development, we predicted that the schizophrenia patients would perform more poorly on the weather prediction task than typically developing controls. Further, we also predicted that this deficit would be related to language-based skills that rely on implicit learning for development (e.g., expressive language, vocabulary, and reading) more so than to other neurocognitive skills.

2. Experimental materials/methods

2.1. Participants

Participants with schizophrenia were recruited from the UCLA Aftercare Research Program, a research program dedicated to providing comprehensive care to individuals within two years of their first episode of psychosis and examining variables contributing to treatment outcome (Nuechterlein et al., 2020). Participants were also recruited on the basis of their previous participation in the UCLA Family Study, a multidisciplinary family study of schizophrenia (Asarnow et al., 2002). All participants had a lifetime diagnosis of schizophreniform disorder, schizoaffective disorder, or schizophrenia. The healthy control group was recruited from the Aftercare Research Program community comparison group through phone calls and emails. To determine eligibility for the UCLA Aftercare Research Program or the UCLA Family Study, schizophrenia patients and the healthy controls received a Structured Clinical Interview for DSM-IV– Patient Version (SCID-I/P) (M. First et al., 2001). Individuals that had a history of brain injury, intellectual disability, or neurological disorders (e.g., brain tumor, stroke, epilepsy/seizure disorder) that affected their cognitive functioning were excluded from the study, as were individuals with a history of drug dependence or alcoholism in the six months prior to the assessment. Additionally, for schizophrenia patients, their psychotic episode was not immediately preceded by a period of drug use that may have triggered the psychosis. More detailed recruitment procedures have been previously described (Fogelson et al., 2010; Nuechterlein et al., 2002).

Participants were included in the study if they were over the age of 18 and could understand both written and spoken English. All participants provided informed consent in accordance with the rules and regulations of the UCLA Institutional Review Board (IRB).

2.2. Weather prediction task (WPT)

All participants were administered a computerized version of the WPT, a probabilistic classification task used to measure cognitive skill learning, specifically rule-based learning. In the WPT, participants were exposed to a card or combination of 2–3 cards, each with a distinct geometric shape that is associated with a fixed probability of predicting one of the levels of a binary outcome: "sunshine" or "rain" (Gomar et al., 2011). The cue strength of each of the 14 resulting stimuli were such that the overall probability associating each cue with sun or rain is 0.756, 0.575, 0.425, and 0.244 across the trials. Each stimulus was present on the screen for approximately 3 s. After the participant made a prediction by pressing a button on the mouse, participants received immediate feedback about the accuracy of their response. The feedback, however, was itself conditional and probabilistic (Foerde et al., 2008; Wagshal et al., 2012). Participants completed ten blocks of 40 trials each.

In blocks two and nine of the task, a second, intentionally distracting task was administered concurrently with the WPT. This second task involves listening to high- or low-pitch tones and counting them while simultaneously making predictions about the weather. The impact of the dual-task condition on the accuracy of predicting the weather from the block two to block nine measures the degree of automaticity the individual has achieved.

2.3. Linguistic and neurocognitive measures

A battery of neurocognitive tests was completed to assess domains of cognitive functioning such as basic attention, processing speed, sequencing, task switching, vocabulary development, reading skills, syntax use, and decoding skills. Attention, processing speed, and sequencing have been hypothesized to interfere with learning more globally, while language-related tasks are thought to be impacted by deficits in implicit learning during development. The battery of tests included two subtests of the Woodcock-Johnson Tests of Academic Achievement III (Letter-Word Identification, Word Attack), three subtests of the Wechsler Adult Intelligence Scale, Fourth Edition (WAIS-IV) (Vocabulary, Digit Span, Coding), two subtests of the Clinical Evaluation of Language Fundamentals, Fifth Edition (CELF-5) (Formulated Sentences, Sentence Assembly), and the Trail Making Test.

2.4. Statistics

Using the GLM approach within IBM SPSS Statistics software, a combination of independent sample *t*-tests and Chi-squared analyses were used to test for significant differences between groups on demographic variables, including age, sex, highest level of parental formal education achieved, race, and ethnicity. A repeated measures ANCOVA covarying for age and sex was used to examine the a priori hypothesis that patients with schizophrenia would show less learning across trial blocks in the WPT than the healthy control participants. Independent sample *t*-tests were also utilized to compare groups on neurocognitive variables, percent accuracy of each block of the WPT, dual task effects, maximum accuracy achieved on any block, learning curve (highest block accuracy – baseline block accuracy), and change in automaticity.

A dual-task interference variable was computed by subtracting accuracy on a dual-task trial from the average accuracy of the trial just before and just after it [e.g., (Block 1 + Block 3)/2 - Block 2]. An individual's relative dual-task performance (e.g., change in automaticity) over the course of the WPT was computed by subtracting Block 2 interference from Block 9 interference to determine how much automaticity was achieved. For within-group analysis, the schizophrenia group was further divided into two groups, those individuals who developed some degree of automaticity (i.e., a decrease in dual-task interference) throughout the WPT and the those who did not.

3. Results

3.1. Demographic characteristics

The demographic characteristics of the schizophrenia and control groups are displayed in Table 1. Age, sex, highest parental education, race, and ethnicity did not significantly differ between the two groups.

3.2. Weather prediction task performance

On the WPT, the schizophrenia group performed above chance in every single-task block but demonstrated very little learning across trials. A repeated measures ANCOVA, covarying age and sex, revealed statistically significant differential learning across trial blocks for the participants in the schizophrenia and control groups, $F = 4.59$, $p = .038$, partial $\eta^2 = 0.096$, with the control group having a steeper linear slope than the schizophrenia group. The control group performed above chance in single-task blocks and continued to improve upon their performance across trials, ultimately surpassing the schizophrenia group (see Fig. 1). In the later blocks, starting with block 4, there is a statistically significant difference between the two groups in every block (Table 2). Significant differences were also found between the two groups in terms of their maximum accuracy during the task (Maximum

Table 1
Demographic information.

	Schizophrenia (*N* = 34)	Control (*N* = 18)			
	Mean (SD)		t/X	df	*p*
Age	28.44 (11.50)	27.4 (7.60)	0.31	50	0.76
Sex	7f, 27f	7f, 11 m	2.18	1	0.14
Highest parental education	13.85 (3.68)	13.94 (2.58)	−0.1	49	0.92
Race			3.13	5	0.68
American Indian/ Alaskan Native	1	2			
Asian	2	0			
Black/African American	7	5			
White	13	7			
More than one race	6	2			
Unknown/not reported	5	2			
Ethnicity			1.06	1	0.3
Hispanic	12	9			
Not Hispanic	22	9			

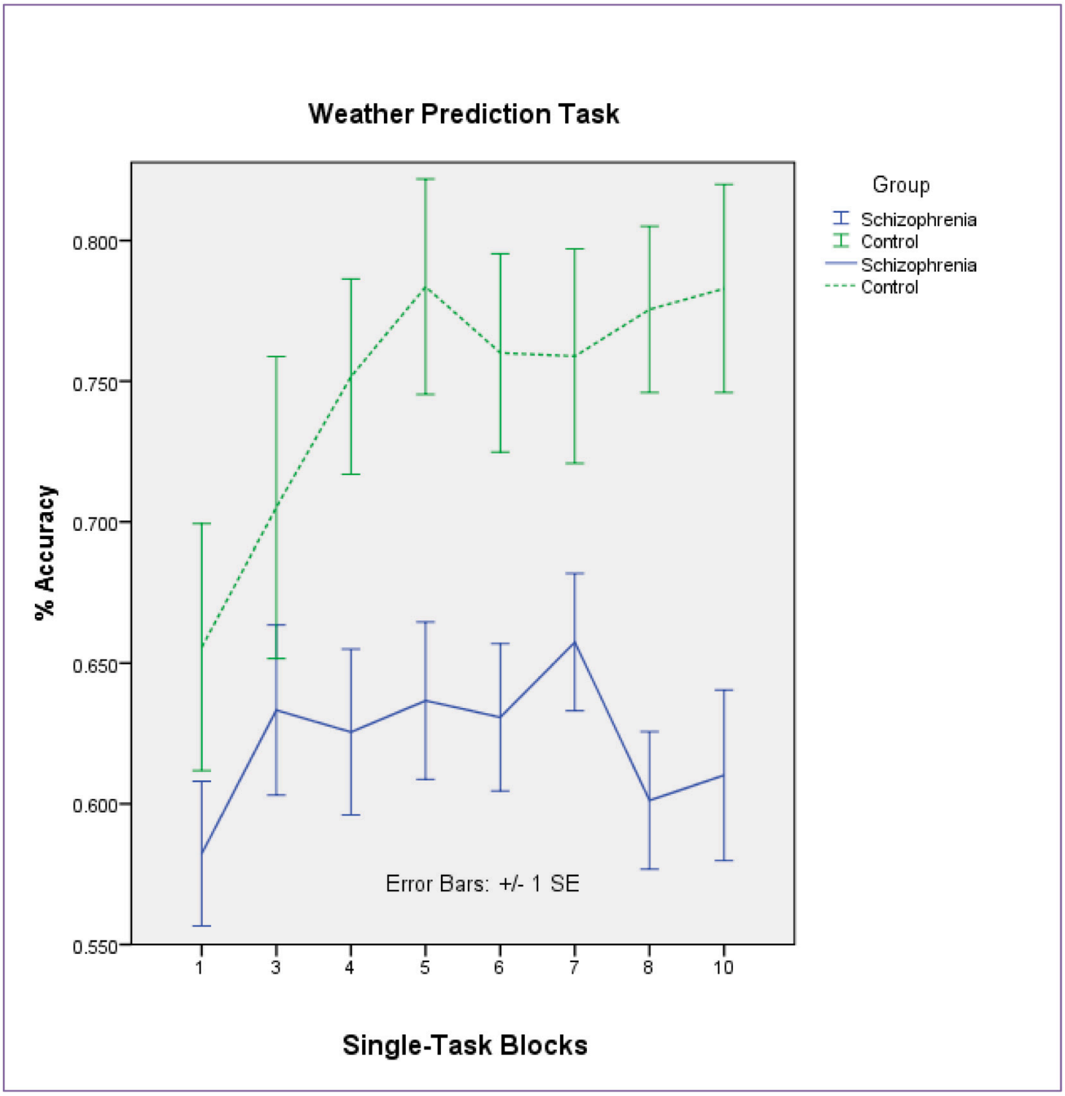

Fig. 1. Weather prediction task performance by group.

Accuracy Achieved, $t = -3.82$, $p < .001$).

Minor differences were evident between the two groups on dual task performance (i.e., Change in Automaticity). The control group demonstrated a slight decline in interference from the distractor task from the early to later blocks of the WPT. The schizophrenia group demonstrated an unusual pattern of dual task performance, where they seemed to experience greater interference from the distractor task in the later blocks of the trial. In the end, these differences were small for both groups, suggesting that, on average, little automaticity was achieved on this brief version of the WPT, and differences in performance between groups were not statistically significant, $t = 0.72$, $p = .477$ (see Fig. 2).

3.3. Group differences

Individuals with schizophrenia demonstrated depressed cognitive functioning relative to the typically developing participants across nearly all cognitive functions, including: Digit Span, $t = -3.51$, $p < .001$; Vocabulary, $t = -2.69$, p 0.010; Coding $= -4.15$, $p < .0001$; Word Attack, $t = -2.66$, $p = .011$; Sentence Assembly, $t = -2.07$, $p = .044$; and Formulated Sentences $= -3.29$, $p = .002$. However, in contrast, the schizophrenia group did not perform significantly different from the typically developing group on Letter-Word Identification, t = =1.89, $p = .64$; Trails A, $t = 1.30$, $p = .200$; or Trails B, $t = 1.67$, $p = .101$.

3.4. Post-hoc analyses

Post-hoc analyses suggested the presence of a subgroup of individuals with schizophrenia who did not develop any automaticity during the repeated blocks of trials ($N = 8$). For patients who demonstrated no development of automaticity over the course of the WPT, overall neurocognitive ability was strongly correlated with their Block 1 WPT performance: Digit Span, $r = 0.77$, $p = .027$; Vocabulary, $r = 0.90$, $p = .003$; Letter Word Identification, $r = 0.84$, $p = .010$; Word Attack, $r = 0.75$, $p = .031$; Formulated Sentences, $r = 0.85$, $p = .007$; Sentence Assembly, $r = 0.80$, $p < .016$. For patients who developed some degree of automaticity, overall neurocognitive ability was correlated with their maximum level of performance (i.e., Maximum Accuracy) on the WPT but not with their Block 1 performance: Digit Span, $r = 0.60$, $p = .004$; Vocabulary, r = 0.60, $p = .004$; Coding, $r = 0.48$, $p = .027$; Letter Word Identification, $r = 0.56$, $p = .008$; Word Attack, $r = 0.45$, $p = .039$; Formulated Sentences, $r = 0.51$, $p = .018$; Sentence Assembly, $r = 0.44$; $p = .047$. These results are summarized in Table 3.

Furthermore, for the group of individuals that who developed automaticity during the WPT, a statistically significant correlation was observed between the Learning Curve and tasks requiring efficient speeded cognitive processing: Coding, $r = 0.53$, $p = .014$ and Trails B time to completion, $r = -0.52$, $p = .017$.

Table 2
Group differences between schizophrenia and typically developing group.

Task	t	df	p
Digit Span	−3.506	48	0.001
Vocabulary	−2.694	48	0.010
Coding	−4.149	48	0.000
Letter-Word Identification	−1.890	48	0.064
Word Attack	−2.663	48	0.011
Sentence Assembly	−2.068	48	0.044
Formulated Sentences	−3.291	48	0.002
Trails A	1.298	48	0.200
Trails B	1.670	48	0.101
WPT			
Single Task Block 1	−1.542	45	0.130
Dual Task Block 2	−1.413	45	0.164
Single Task Block 3	−1.262	45	0.214
Single Task Block 4	−2.625	45	0.012
Single Task Block 5	−3.082	45	0.004
Single Task Block 6	−2.916	45	0.006
Single Task Block 7	−2.326	45	0.025
Single Task Block 8	−4.341	45	0.000
Dual Task Block 9	−2.751	45	0.009
Single Task Block 10	−3.460	45	0.001
Early Dual Task Effect	−0.455	45	0.651
Late Dual Task Effect	−1.357	45	0.182
Maximum Accuracy Achieved	−3.818	45	0.000
Learning Curve	−1.051	45	0.299
Change in Automaticity	0.718	45	0.477

Noting correlations with measures of working memory, group differences in performance between task accuracy in later blocks and were further analyzed. No statistically significant differences in single-task accuracy at Block 10 were found. An additional analysis of this data reveals that Block 9 accuracy (i.e., the second dual-task block which occurs later in the task) is correlated with Digit Span performance in participants with development of automaticity ($r = 0.527, p = .014$) and not for those without development of automaticity ($r = 0.286, p = .455$).

The two subgroups of individuals with schizophrenia that did and did not develop automaticity did not demonstrate statistically significantly differences in their performance on the linguistic and neurocognitive measures. Likewise, task accuracy on single-task measures did not differ between groups.

4. Discussion

Although some previous findings have suggested that schizophrenia patients are able to perform probabilistic classification tasks such as the WPT with preserved accuracy (Kéri et al., 2000), the present study was consistent with others that show reduced accuracy in the schizophrenia group across trials (Weickert et al., 2002; Foerde et al., 2008). Further, these findings are consistent with those other studies that have found differential learning between the schizophrenia and control groups, with schizophrenia patients performing just above chance and failing to show much increase in accuracy during the course of the task (Foerde et al., 2008).

We did not find a significant difference between schizophrenia and healthy groups in the development of automaticity, based on changes in dual-task interference over trials. A factor that may play a role in the discrepant automaticity findings outcomes across studies may be the numbers of trials employed. Some versions of the WPT involve several hundred trials across multiple sessions (Foerde et al., 2008), whereas others were relatively brief (e.g., 50 trials) (Kéri et al., 2000). A small number of trials is adequate if the goal of the task is to measure accuracy and learning, as a consistent finding across probabilistic classification learning tasks is that the control group usually makes rapid gains in accuracy, usually plateauing or slowing down considerably after the first 50 trials or so of the task (Foerde et al., 2008; Wagshal et al., 2012; Wagshal et al., 2014). However, the use of only relatively few trial blocks is likely inadequate if the primary goal of the study is to measure automaticity, as participants tend to recruit explicit learning strategies in early learning trials and the more subtle effects of implicit learning

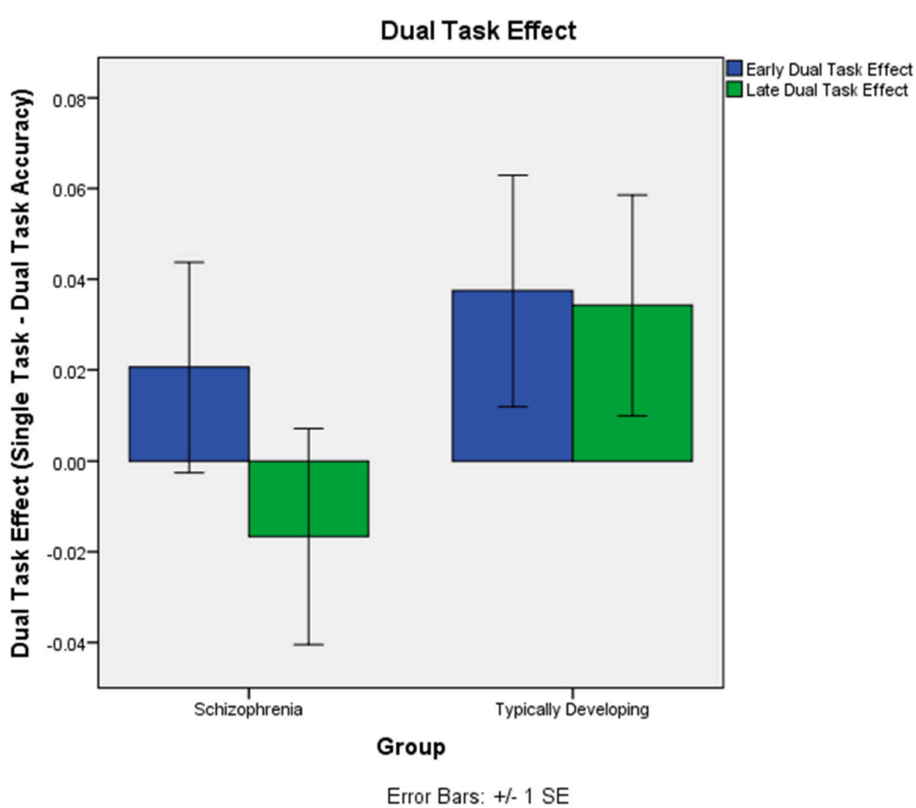

Fig. 2. Early and late dual task effect by group.

Table 3
Correlation between WPT automaticity and cognitive performance in schizophrenia group.

	No automaticity development			Improved automaticity		
	N = 8			N = 21		
	Block 1 accuracy	Maximum accuracy	Learning curve	Block 1 accuracy	Maximum accuracy	Learning curve
Digit Span	0.765*	0.212	−0.514	0.201	0.597**	0.320
Vocabulary	0.897**	−0.076	−0.816*	0.280	0.603**	0.248
Coding	0.630	0.252	−0.372	−0.115	0.482*	0.526*
Letter Word Identification	0.837**	0.109	−0.643	0.119	0.564**	0.370
Word Attack	0.753*	0.263	−0.470	0.005	0.454*	0.386
Formulated Sentences	0.851**	−0.205	−0.862**	0.186	0.509*	0.259
Sentence Assembly	0.803*	0.281	−0.501	0.161	0.437*	0.221
Trails A	−0.530	−0.319	0.243	0.186	−0.274	−0.415
Trails B	−0.578	−0.346	0.265	0.185	−0.392	−0.516*

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

are only observed later in practice. The present study demonstrates that potential limitation as little measurable difference was found in degrees of automaticity between the schizophrenia group and the control group.

An analysis of cognitive performance between groups suggested that impaired WPT performance could be the result of gross deficits in cognitive functioning. However, it is important to note that these differences could not be accounted for by differences in basic attention, processing speed, sequencing, and task-switching as differences between the patient and control groups on Trails A and B were not statistically significant. Likewise, reductions in WPT accuracy have also been found among schizophrenia and control groups with similar scores on the Wisconsin Card Sorting Task (Weickert et al., 2002). That the two schizophrenia subgroups demonstrated a deficit in all language-based tasks could be potentially relevant to WPT accuracy, as others have hypothesized that the various receptive language deficits found in schizophrenia have a neurodevelopmental etiology (Condray, 2005) and language dysfunction is a core feature of childhood-onset schizophrenia (Caplan et al., 1989; Caplan et al., 1996). Correlation analysis within schizophrenia subgroups provide some evidence for that possibility, as tasks involving auditory/verbal processing, vocabulary development, syntax, and literacy skills were related to the degree of accuracy achieved on the WPT. Other tasks showing a relation to automaticity (i.e., Coding) measure processing speed but also tap into working memory to make symbol/number associations, a process mediated by verbal strategies (e.g., "this number goes with that symbol"). This set of analyses provides further support for the use of auditory/verbal strategies, which are explicit and maintained by rehearsal, are important for initial rapid improvement in accuracy on WPT.

While the ability to engage in implicit learning may have accounted for individual differences in the ability to acquire linguistic skills during development, there is not a clear indication that this is the reason WPT performance was related to the various cognitive variables examined in the study, particularly because the cognitive tasks in the study utilize both implicit and explicit processes during their development. For example, vocabulary is likely learned explicitly while syntax (i.e., Formulated Sentences) likely relies more heavily on implicit process. In fact, the relationship between linguistic abilities and implicit learning is likely bi-directional. By the same token, both implicit and explicit processes are utilized in completion of the WPT. In future research, cross-sectional studies in adults with schizophrenia could be extended very meaningfully by comparisons to adults with child-onset schizophrenia and particularly by longitudinal study of language functioning in children at-risk for developing the disorder.

A measure of working memory, Digit Span, was included in the analysis to rule out the possibility that the results of the WPT, especially the analysis of automaticity, could be accounted for by the working memory burden alone. Correlations between this measure and WPT performance (i.e., single-task accuracy) in the groups of schizophrenia patients that did and did not develop automaticity suggests that, in addition to linguistic abilities, auditory/verbal attention and working memory play a role in development of automaticity.

Variability in methodology and heterogeneity among samples due to variable symptomology among schizophrenia patients may play a role in the differing findings with respect to accuracy and learning trajectory on the WPT. Despite converging evidence that individuals with schizophrenia perform probabilistic classification tasks differently than their matched controls, little has been done to identify the underlying cognitive processes that may be contributing to probabilistic classification learning in the schizophrenia group. In the present study, it seems that lower overall cognitive ability is associated with poor WPT performance early in practice for patients unable to use repeated trials to develop automaticity. This provides additional support for the suggestion that early performance on procedural learning tasks importantly involves explicit learning. For schizophrenia patients who develop at least partial automaticity, overall cognitive ability does not significantly impact initial WPT performance but may limit later maximum accuracy. Thus, overall cognitive ability plays a role in WPT performance in schizophrenia, but how it limits performance is dependent on the ability to develop automaticity.

Contributors

Vindia Fernandez developed the proposal that resulted in the present research as part of a postdoctoral training grant under the guidance of Keith Nuechterlein and Robert Asarnow. She collected the data, undertook the statistical analysis, and drafted the manuscript. Keith Nuechterlein and Robert Asarnow guided the development of the research plan, supervised the data collection, and assisted with data analysis and editing of the present manuscript. Megan Hodges assisted with the literature review as part of her undergraduate research. All authors contributed to and have approved the final manuscript.

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Declaration of competing interest

None of the authors have any actual or potential financial, personal, or other conflicts of interest to disclose. Dr. Nuechterlein has research support for other projects from Janssen Scientific Affairs, Posit Science, and Stanley Medical Research Institute and has been a consultant to Astellas, Genentech, Janssen, Otsuka, Takeda, and Teva.

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