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Grammatical processing in schizophrenia: Evidence from morphology

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ABSTRACT

Patients with psychiatric disorders such as schizophrenia commonly present with impaired language. Here we investigate language in schizophrenia with a focus on inflectional morphology, using an intensively studied and relatively well-understood linguistic paradigm. Patients with schizophrenia ($n=43$) and age-matched healthy control subjects ($n=42$) were asked to produce past tenses of regular (*slip*), irregular (*swim*), and novel (*plag*) English verbs. Patients were impaired at regulars and novels (*slipped, plagged*), with relative sparing of irregulars (*swam*), controlling for numerous subject- and item-specific factors (e.g., IQ, phonological complexity). Additionally, patients' thought-disorder scores significantly predicted their performance at regular and novel (but not irregular) past-tense production. The results support grammatical deficits in schizophrenia, with a relative sparing of lexical memory, and suggest that thought disorder may be linked with grammatical impairments in the disorder.

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1. Introduction

Schizophrenia is strongly associated with language problems, including (but not limited to) poverty of speech (alogia) and disorganized speech. Language abnormalities are part of the diagnostic criteria for schizophrenia, and a range of studies have examined language in the disorder. Here we employ a well-studied language paradigm in an effort to elucidate the language profile in schizophrenia, and to examine how this profile relates to other cognitive functions associated with the disorder.

1.1. Idiosyncratic vs. rule-governed linguistic knowledge

Language depends both on idiosyncratic knowledge (e.g., unpredictable form-meaning mappings) and rule-governed knowledge (e.g., predictably structured form-meaning mappings). This distinction between rule-governed and idiosyncratic aspects of language has been widely studied in a paradigm that contrasts two types of morphological mappings: regular (described by a default rule; e.g., *-ed*-affixation in English past tense formation) and irregular (idiosyncratic, unpredictable mappings; e.g., for irregular past tense forms: *bring-brought, sing-sang*) (Joanisse & Seidenberg, 1999; Pinker, 1999; Pinker & Ullman, 2002; Rumelhart & McClelland, 1986; Ullman, 2001; Ullman et al., 1997). According to "dual-system" models, irregular past tense forms (e.g., *sprang*) always depend on the mental lexicon, whereas real and novel regular past tenses (e.g., *walked, blicked*) are generally computed by the mental grammar, which combines verb stems (e.g., *walk*) with affixes (e.g., *-ed*) (Pinker, 1999; Pinker & Ullman, 2002; Ullman, 2001; Ullman et al., 1997). Note, however, that regular past-tense forms *could* be memorized in the mental lexicon, and indeed are under various conditions, such as high frequency regulars, or – of particular interest here – as a compensatory mechanism in the face of grammatical deficits (Alegre & Gordon, 1999; Prado & Ullman, 2009; Ullman & Pierpont, 2005; van der Lely & Ullman, 2001). Such memorization can be detected by testing for "frequency effects" (e.g., faster or more accurate responses to more frequent forms) for regular inflected forms. Frequency effects suggest storage – and indeed they are consistently found for irregular inflected forms, which must be stored – whereas the absence of such effects suggests a lack of storage.

Evidence has linked the mental lexicon and the mental grammar to distinct neurocognitive systems. According to the dual-system Declarative/Procedural model, the mental lexicon depends on the declarative memory system, whereas the mental grammar relies on

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the procedural memory system (Ullman, 2001, 2004, 2008; Ullman et al., 1997): Evidence suggests that the declarative memory system, which underlies the learning and use of knowledge about facts ("semantic memory") and personally experienced events ("episodic memory"), also underlies the learning and use of lexical knowledge, including for irregular morphological forms. The procedural memory system, which is implicated in the learning of new and the control of long-established motor and cognitive "skills" and "habits", also subserves aspects of the learning and use of grammar, including in the inflection of real and novel regular morphological forms.

1.2. Language and related systems in schizophrenia

Since the seminal investigation of language in schizophrenia by Kleist (1914), who reports deficits in affected patients in multiple areas of language, including morphology, we are aware of only a few brief mentions of morphological abnormalities in the literature (Covington et al., 2005; DeLisi et al., 1997). However, other aspects of language have been well-studied in schizophrenia, including lexical and grammatical – particularly syntactic – functions (for reviews, see Covington et al., 2005; DeLisi, 2001). Many studies report deficits on "grammar" tasks that require syntactic processing, in both production (e.g., arrange words to form a sentence) and comprehension (e.g., the Token Test) (Condray, Steinhauer, van Kammen, & Kasparek, 2002; Covington et al., 2005; DeLisi et al., 1997; Faber & Reichstein, 1981; Fraser, King, Thomas, & Kendell, 1986; Lelekov, Franck, Dominey, & Georgieff, 2000). Impairments in lexical performance have also commonly been reported, for both expressive and receptive tasks (Bokat & Goldberg, 2003; Faber & Reichstein, 1981; Goldberg et al., 1998; Joyce, Collinson, & Crichton, 1996; Landre, Taylor, & Kearns, 1992; Phillips, James, Crow, & Collinson, 2004). However, evidence suggests that while lexical knowledge may become disorganized and/or difficult to access, the knowledge itself might not be affected in schizophrenia (Aloia, Gourovitch, Weinberger, & Goldberg, 1996; Covington et al., 2005; Tallent, Weinberger, & Goldberg, 2001).

The status of grammar and lexicon in schizophrenia may be at least partly paralleled by that of procedural and declarative memory in the disorder. Patients with schizophrenia have shown worse performance (i.e., slower, less accurate responses) than healthy controls on tasks tapping the procedural memory system, even when general cognitive abilities are taken into account, although procedural learning itself appears to be spared (Keri et al., 2000; Weickert et al., 2002). Patients with schizophrenia seem to show a somewhat different pattern for declarative memory: Knowledge learned in declarative memory early in childhood (prior to disease onset) appears to remain essentially normal (Dalby & Williams, 1986; Weickert et al., 2000), whereas deficits are found at learning new knowledge in this system (Goldberg & Weinberger, 1996; Nuechterlein et al., 2004; Weickert et al., 2000).

Thus although patients appear to have deficits at learning in declarative memory but not procedural memory, they show a different pattern at tasks that do not tap learning, a pattern that may at least partly parallel that found in language: The processing of both grammar and non-linguistic knowledge in procedural memory appears to be impaired, whereas both lexical knowledge and non-linguistic knowledge that is learned early in childhood appear to remain relatively spared. This leads to specific predictions regarding regular and irregular inflectional morphology: Processing regular and novel verbs (e.g., *walked, blicked*) should be impaired, while irregular past tenses (e.g., *teach-taught*) should remain relatively spared.

1.3. Thought disorder

Grammatical as well as lexical deficits in some patients with schizophrenia who display disorganized speech have been associated with "thought disorder," defined as an inability to logically combine thoughts into sentences and sentences into coherent discourse (Aloia et al., 1998; Andreasen, 1986; Goldberg et al., 1998; Sanders, Adams, Tager-Flusberg, & Shenton, 1995; Spitzer, 1997). Studies have found that a greater degree of thought disorder is associated with worse performance both in tasks probing syntactic abilities (Faber & Reichstein, 1981; Fraser, King, & Thomas, 1989) as well as those examining lexical abilities (Aloia et al., 1998; Faber & Reichstein, 1981; Goldberg et al., 1998; Spitzer et al., 1994). It has also been suggested that thought disorder reflects a general cognitive dysfunction which may only indirectly result in the appearance of impaired language (Blakey, Hellewell, & Deakin, 1996; Rodriguez-Ferrera, McCarthy, & McKenna, 2001).

1.4. The present study

Patients with schizophrenia and healthy control subjects were asked to produce past-tense forms of regular (e.g., *shrug*), irregular (e.g., *drive*), and novel (e.g., *plag*) verbs. We expected greater deficits for patients, *relative to* controls, at the production of -*ed*-affixed regular and novel past tenses than at the production of irregular past tenses. However, patients with schizophrenia may be able to compensate for a deficit on regular verbs by memorizing them, given sufficient time post-disease onset. In this case, there may be

Table 1
Demographic and neuropsychological characteristics of patients with schizophrenia and healthy controls.

	Patients with schizophrenia	Healthy controls	Difference
N	43	42	–
Sex	33 M/10 F	19 M/23 F	Fisher's exact $p = 0.004$
Handedness	38 R/4 L/1 mixed	34 R/6 L	Fisher's exact $p = 0.23$
Age	35.3 (8.6)	35.0 (10.6)	$t(83) = 0.13$, $p = 0.89$
Education (years)	14.1 (2.0)	15.9 (1.9)	$t(83) = 4.21$, $p < .0001$
WRAT-R Reading	103.5 (10.2)	110.1 (6.3)	$t(76) = 3.60$, $p = 0.0006$
WAIS-R FSIQ	92.7 (11.7)	107.1 (9.2)	$t(77) = 6.30$, $p < 0.0001$
Illness onset (age)	22.3 (4.8)	–	–
Illness duration (years)	13.0 (8.3)	–	–
TLC global score	1.8 (1.1)	–	–

Notes. Means (and standard deviation) are shown. WRAT-R = Wide Range Achievement Test-Revised. TLC = thought, language, and communication scale global thought-disorder rating score. Handedness information was not available for two of the controls; missing values were imputed in separate tests as either both left- or both right-handed. The two imputations each resulted in non-significant group differences (reported here with the left-handed imputation). Group differences in age, education, and WRAT-R Reading scores were assessed using unpaired *t*-tests. As WRAT-R reading scores were not available for 7 of the controls, we imputed the missing values using a "best" imputed value, calculated from a regression equation established for the non-missing WRAT-R scores on the basis of the age, education, and sex of the controls. We also imputed the missing values as either the 10th or the 90th percentile score from the full distribution of values (across both subject groups). The same procedure was followed for WAIS-R full scale IQ scores, which were not available for 6 of the controls. No differences were found for different imputations (reported using the "best" imputation). Illness onset and duration were not available for one patient. TLC scores were not available for seven patients.

Table 2
Verbs in the past tense production task.

Verb type	Verbs (expected past tense response)
Regular:	chop (chopped), cook (cooked), cross (crossed), drop (dropped), flap (flapped), frown (frowned), look (looked), pass (passed), rob (robbed), roll (rolled), rush (rushed), scour (scoured), scowl (scowled), shrug (shrugged), slam (slammed), slip (slipped), soar (soared), stalk (stalked), stir (stirred), walk (walked)
Novel:	brop (bropped), crog (crogged), cug (cugged), dotch (dotched), grush (grushed), plag (plagged), plam (plammed), pob (pobbed), prap (prapped), prass (prassed), satch (satched), scash (scashed), scur (scurred), slub (slubbed), spuf (spuffed), stof (stoffed), trab (trabbed), traf (traffed), tunch (tunched), vask (vasked)
Irregular:	bend (bent), bind (bound), bite (bit), cling (clung), dig (dug), drive (drove), eat (ate), feed (fed), keep (kept), lose (lost), make (made), ride (rode), sell (sold), send (sent), sleep (slept), stand (stood), swim (swam), swing (swung), think (thought), wring (wrung)

Notes. Correct responses (with plausible spelling for novel responses, though all response coding used phonemic representations) are in parentheses following each verb.

no apparent deficit on regulars (though a deficit on novels would still be expected, since these forms could not have been memorized), and patients (though not controls) may show frequency effects for regular past tense forms. Alternatively, such compensation might not be a viable option for patients; for example, learning impairments in declarative memory (see above) would suggest that memorization of regular past-tense forms may be unlikely after disease onset. Finally, given the mixed literature on the relation among thought disorder and lexical and grammatical impairments in schizophrenia, we had no predictions about the relation between thought disorder and performance on the past-tense production task.

2. Methods

2.1. Participants

Forty-three patients with a diagnosis of schizophrenia (21 inpatients, 22 outpatients) participated in this study (Table 1). Four additional patients with schizophrenia were initially included in the study, but were unable or unwilling to perform the past-tense production task (answering fewer than 10% of all items correctly), and are not included here. All remaining participants had overall accuracies of at least 40%. Two board-certified psychiatrists blind to the neuropsychological evaluations and experimental test scores concurred on diagnosis, per the Structured Clinical Interview for the DSM-IV (SCID-I; First, Spitzer, Gibbon, & Williams, 1996). Patients receiving concurrent axis I psychiatric diagnoses other than schizophrenia, or having a history of substance abuse, head injuries (with concomitant loss of consciousness), seizures, central nervous system infection, diabetes, or hypertension were not included. Of the 43 patients, 12 were classified as undifferentiated, 13 as paranoid, 5 as disorganized, 3 as residual subtypes of schizophrenia, and 6 as having schizoaffective disorder. The remaining patients were classified with the following alternative dimension or research-related diagnoses, based on DSM-IV: 2 as chronic, 1 as simple, and 1 as typical schizophrenia.

The majority of the patients (35/43) were receiving second generation antipsychotic medication (clozapine $n=8$, clozapine and lithium $n=1$, clozapine and ziprasidone $n=1$, olanzapine $n=13$, olanzapine and risperidone $n=3$, quetiapine $n=1$, risperidone $n=6$, olanzapine and thioridazine $n=1$, and quetiapine and haloperidol $n=1$), while the remaining patients were receiving only first generation antipsychotic medication alone (fluphenazine $n=1$, haloperidol $n=1$, and loxapine $n=1$), lithium alone ($n=1$) or no antipsychotic medication ($n=4$) at the time of testing.

In addition to patients with schizophrenia, 42 healthy controls recruited through the National Institutes of Health Normal Volunteer Office participated in this study. Any controls with a history of psychiatric disorders, current substance abuse, head injuries (with concomitant loss of consciousness), seizures, central nervous system infection, diabetes, or hypertension were excluded.

All patients and controls provided informed written consent prior to participation. The Institutional Review Boards of both Georgetown University Medical Center and the National Institute of Mental Health provided approval for this study.

2.2. Demographic information and neuropsychological assessment

All patients and controls were native English speakers of standard American English; 88% of the patients and 80% of the controls were Caucasian. Handedness was assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). Estimates of premorbid IQ scores were based on the Reading subtest of the Wide Range Achievement Test-Revised (WRAT-R) (Jastak & Wilkinson, 1984), which measures phonological knowledge (reading for pronunciation) that is typically acquired early during development (Wechsler, 1958). Scores from this test strongly correlate with overall intellectual ability in controls (Wiens, Bryan, & Crossen, 1993) and are thought to remain stable in patients with schizophrenia (Dalby & Williams, 1986; Kremen et al., 1996; Nelson et al., 1990), providing a valid assessment of premorbid intellectual function relative to other IQ test scores, which typically display significant declines following illness onset (Schwartzman & Douglas, 1962; Weickert et al., 2000). Estimated current IQ scores (FSIQ) were assessed using a four-subtest version of the Wechsler Adult Intelligence Scale-Revised (WAIS-R) (Wechsler, 1981): the Arithmetic, Digit Symbol Substitution Test (DSST), Picture Completion, and Similarities subtests (Kaufman & Lichtenberger, 2005; Missar, Gold, & Goldberg, 1994; Weickert et al., 2000). Thought disorder was assessed (in patients) using the Thought, Language, and Communication (TLC) Scale, which provides ratings that range from 0 (no thought disorder) to 4 (extreme thought disorder) (Andreasen, 1986). Global thought-disorder ratings for each patient were obtained within 1 week from administration of the past tense production task, during a group interview in which a consensus was reached by two to three psychologists trained in administration of the TLC.

2.3. Past tense production task

The materials, design, and procedure for this task are based on those used in previous studies; for details see Ullman et al. (1997, 2005). Sixty monosyllabic verbs were included in the study (Table 2): 20 real verbs with an irregular past tense (*drive-drove*), 20 real verbs with a regular past tense (*shrug-shrugged*), and 20 novel verbs (*plag-plagged*). Stems of regular and novel verbs were phonologically dissimilar to the stems of existing irregular verbs. Regular and irregular verbs were matched group-wise on past-tense surface frequency, based on the combination of two frequency counts: Francis and Kucera (FK) (Francis & Kucera, 1982), and a count generated by a stochastic part-of-speech analyzer from the 1988 unedited Associated Press newswires (AP) (Church, 1988; Ullman, 1999). Natural-log transformed frequency scores did not differ significantly between the regular and irregular verbs (Table 3).

Subjects were instructed to read each sentence pair aloud, filling in the missing form of the verb in a sentence context designed to elicit a past tense form; e.g., "Every day I *drive* my car. Just like every day, yesterday I ______ my car." All responses were transcribed during testing by the experimenter. If participants misread a verb in the first sentence, they were asked to reread the entire sentence again (this occurred only for one patient on one item). Regular, irregular, and novel items were intermixed, within a single presentation order that was the same for each subject.

2.4. Response coding

Only subjects' first responses were scored and analyzed; any subsequent responses were omitted. Correct responses for real verbs and regularized responses

Table 3
Item-specific factors for the past tense production task.

Variable	Regular verbs	Novel verbs	Irregular verbs	Difference
Ln (past tense frequency)	5.2 (2.0)	–	5.9 (2.2)	$F(1,38)=1.64$, $p=0.28$
Past tense length (phonemes)	4.5 (0.5)	4.8 (0.4)	3.6 (0.7)	$F(2,57)=26.15$, $p<0.0001$
Verb imageability	4.0 (0.4)	–	3.7 (0.8)	$F(1,38)=2.83$, $p=0.10$
Phonological neighborhood	3.05 (1.6)	2.5 (3.2)	−5.6 (7.4)	$F(2,57)=20.6$, $p<0.0001$
Consistent rime voicing	20/20	20/20	15/20	Fisher's exact $p=0.009$

Notes. Means (and standard deviation) are provided for each verb type for item-specific factors of interest. Differences were evaluated by a Fisher's exact test for the consistent rime voicing factor, and by one-way ANOVAs for the continuous factors. Factors that were unbalanced ($p\leq 0.10$) were tested further as potential covariates (see Section 2.5 in text for further details).

for novel verbs (classified as 'correct') are displayed in Table 2. Incorrect responses for real verbs, and non-regularized responses for novel verbs, were categorized as one of several mutually exclusive error types, as shown in Table 4 (Ullman et al., 1997, 2005). No other types of errors or responses were made by patients or controls.

Errors classified as 'regularized' forms (for irregular verbs only) had the appropriate allomorph of the regular past tense ending *-ed* added to the exact form of the stem given to the subject (e.g., *drive-drived; make-maked*). A response was categorized as an 'irregularized' (for regular and novel verbs) or 'over-irregularized' (for irregular verbs) error if the form was similar to stem-past changes of English irregular verbs (Ullman et al., 2005) (*cling-clang; spuf-spaf*). A response was coded as an 'unmarked' error if the subject repeated the presented verb stem exactly (*drive-drive*); as an 'inflection error' if the subject produced a non-*ed*-suffixed form of the given stem (*drives; driving*); or as a 'double-marked' error if the form consisted of an irregular(ized) response that was *-ed*-affixed (*drive-droved, shrug-shragged*). Responses to regular, irregular, or novel verbs that appended more than one correct allomorph of the regular-*ed* suffix to the given stem form were coded as 'multiple-ed' errors (*driveded; plaggeded; shruggeded*). A real word response that was not a form of the given stem was coded as an 'intrusion' error (*shrug-guess, plag-fished, drive-laughed*). A response was coded as a 'distortion' if it contained a small number of phonological changes (typically consonant omissions or additions) to the stem that were *not* consistent with any plausible attempt at an (over-)irregularization of the stem (*pob-probbed, shrug-shug, drive-drifed*). Finally, a lack of any response at all was coded as a 'no response' error.

2.5. Data analysis

2.5.1. Past tense accuracy

We analyzed the data using a generalized hierarchical linear model (HLM) with a logit link function, designed for binary-outcome data (also known as random coefficient logistic regression). Such models allow for each individual response from each subject to be entered into a single model, avoiding the substantial loss of information entailed by the data averaging required in the computation of percent correct scores. Additionally, this technique allows for a single statistical model to more precisely account for multiple sources of variance, such as variance due to both subject-specific characteristics, such as IQ, and item-specific characteristics, such as word length (Baayen, 2004; Walenski, Mostofsky, & Ullman, 2007).

Our main factors of interest were subject group (patient, control), and verb type (regular, irregular, novel). We also examined multiple subject- and item-specific factors which could potentially influence performance on past-tense production. The six subject-specific factors were (Table 1): sex, handedness, age, years of education, WRAT-R reading scores, and WAIS-R FSIQ scores. Five item-specific factors were examined (Table 3): past-tense frequency (as computed for frequency matching; see above), past tense length (computed as the number of phonemes; Prado & Ullman, 2009), verb imageability (Bird, Howard, & Franklin, 2003; Bird, Lambon Ralph, Seidenberg, McClelland, & Patterson, 2003; Prado & Ullman, 2009), that is, the imageability of the uninflected form of the verb, using ratings from 1 (low imageability) to 5 (high imageability) (Prado & Ullman, 2009), as well as two additional phonological factors, described as follows.

First, we examined a phonological measure to assess the influence of a verb's "phonological neighborhood" (Prado & Ullman, 2009; Walenski et al., 2007). For example, the production of *sang* from *sing* may be strengthened by similar stem-past pairings such as *spring-sprang*, but weakened by *bring-brought* and *wing-winged*. A verb's (e.g., *sing-sang*) neighborhood strength was calculated as the sum of the (unlogged) past-tense frequencies (total of the Francis and Kucera and Associated Press frequency counts) of verbs of the same verb type (i.e., regular or irregular, with novels treated as regular) that share the same stem rhyme (nucleus and coda) and past-tense rhyme, that is, that have the same stem-past transformation (e.g., *spring-sprang*) *minus* the summed frequencies of any verbs that have the same stem rime but a different stem-past transformation (e.g., *bring-brought*; *wing-winged*). The absolute value of the resulting total was then natural-log transformed – first adding one, to avoid ln(0) – with the negative sign restored to negative frequency totals.

Second, we examined a factor capturing whether the rime of the past tense form exhibited consistent voicing or not (e.g., the rime of the regular past-tense *felled* is consistently voiced, as both /l/ and /d/ are voiced, whereas the rime of the irregular past-tense *felt* is not, as /t/ is voiceless). It has been argued that consistently voiced phonemes within a coda may be less perceptually distinct than inconsistently voiced phonemes, potentially accounting for differences in performance between regular – real or novel – past tenses (always consistently voiced) and irregular past tenses (not always consistently voiced) (Bird, Lambon Ralph, et al., 2003).

To evaluate whether each of these factors could influence the results, we included as covariates in the regression models only those factors that were *both* unbalanced (differs between subject groups or verb types; $p \leq 0.10$; see Tables 1 and 3) and that independently predicted past tense accuracy ($p \leq 0.10$; see below).

All factors were unbalanced except handedness, age (Table 1) and past-tense frequency (Table 3). We tested each of the unbalanced factors in separate logistic regression models that included subject as a random effect, the covariate as a (fixed

Table 4
Accuracy and error rates on the past tense production task for patients and controls.

Error type	Patients	Controls	*t*-Tests
Regular verbs (*shrug*)			
Correct (*shrugged*)	84.9% (2.6)	95.6% (1.1)	(See main text)
Irregularized (*shrag*)	0.1% (0.1)	0	$t_{1s}(42) = 1.00$, $p = 0.32$; $t_2(19) = 1.00$, $p = 0.32$
Unmarked (*shrug*)*	12.7% (1.1)	4.2% (0.7)	$t_{1s}(59.2) = 3.24$, $p < 0.005$; $t_2(19) = 5.25$, $p < 0.0001$
Inflection error (*shrugs*)	0	0	na
Double-marked (*shragged*)	0	0	na
Multiple-ed (*shruggeded*)	0.2% (0.2)	0	$t_{1s}(42) = 1.43$, $p = 0.16$; $t_2(19) = 1.45$, $p = 0.16$
Distortion (*shug, shugged*)	0.3% (0.2)	0	$t_{1s}(42) = 1.77$, $p = 0.08$; $t_2(19) = 1.00$, $p = 0.32$
Intrusion (*guess, guessed*)*	1.5% (0.8)	0.2% (0.2)	$t_{1s}(46) = 1.65$, $p = 0.10$; $t_2(19) = 2.76$, $p = 0.01$
No response	0.2% (0.2)	0	$t_{1s}(42) = 1.00$, $p = 0.32$; $t_2(19) = 1.45$, $p = 0.16$
Novel verbs (*plag*)			
Correct (*plagged*)	80.7% (3.4)	94.4% (1.1)	(See main text)
Irregularized (*plog*)	0.2% (0.1)	0.1% (0.1)	$t_{1s}(76.6) = 0.56$, $p = 0.57$; $t_2(19) = 0.97$, $p = 0.34$
Unmarked (*plag*)*	11.0% (2.4)	3.3% (0.9)	$t_{1s}(54.2) = 2.99$, $p < 0.005$; $t_2(19) = 4.95$, $p < 0.0001$
Inflection error (*plags*)	0	0	na
Double-marked (*plogged*)	0.6% (0.4)	0.4% (0.2)	$t_{1s}(63.7) = 0.52$, $p = 0.60$; $t_2(19) = 0.96$, $p = 0.34$
Multiple-ed (*plaggeded*)	1.0% (0.8)	0.2% (0.2)	$t_{1s}(48.7) = 0.92$, $p = 0.36$; $t_2(19) = 2.30$, $p = 0.03$
Distortion (*splag, splagged*)	1.2% (0.4)	0.7% (0.3)	$t_1(83) = 0.87$, $p = 0.38$; $t_2(19) = 0.85$, $p = 0.40$
Intrusion (*fish, fished*)*	4.2% (1.5)	0.8% (0.4)	$t_{1s}(49) = 2.09$, $p = 0.04$; $t_2(19) = 6.15$, $p < 0.0001$
No response	1.0% (1.0)	0	$t_{1s}(42) = 1.00$, $p = 0.32$; $t_2(19) = 3.94$, $p < 0.001$
Irregular verbs (*drive*)			
Correct (*drove*)	87.9% (1.3)	93.6% (1.1)	(See main text)
Regularized (*drived*)	3.8% (0.7)	2.6% (0.6)	$t_1(83) = 1.13$, $p = 0.26$; $t_2(19) = 1.12$, $p = 0.27$
Over-irregularized (*drave*)	5.2% (0.8)	2.5% (0.5)	$t_{1s}(76.7) = 2.96$, $p < 0.005$; $t_2(19) = 1.40$, $p = 0.17$
Unmarked (*drive*)	2.2% (0.5)	1.0% (0.3)	$t_{1s}(62.2) = 1.46$, $p = 0.14$; $t_2(19) = 1.83$, $p = 0.08$
Inflection error (*drives*)	0.1% (0.1)	0	$t_{1s}(42) = 1.00$, $p = 0.32$; $t_2(19) = 1.00$, $p = 0.32$
Double-marked (*droved*)	0	0.1% (0.1)	$t_{1s}(41) = 1.00$, $p = 0.32$; $t_2(19) = 1.00$, $p = 0.32$
Multiple-ed (*driveded*)	0	0	na
Distortion (*drife, drifed*)	0	0	na
Intrusion (*laugh, laughed*)	0.7% (0.5)	0.2% (0.2)	$t_{1s}(51.6) = 0.89$, $p = 0.37$; $t_2(19) = 1.42$, $p = 0.17$
No response	0	0	na

Notes. Means (and standard error of the mean) are provided. For analysis of errors, we used *t*-tests (patient vs. control) on response rates (as a percent of responses) on each type of response, with subjects (t_1) and items (t_2) as error terms. The Satterthwaite approximation was used to estimate degrees of freedom (t_{1s}) in unpaired tests when significant folded-*F* tests indicated unequal variance. Group differences ($p \leq 0.10$ both by-subjects and by-items) on errors indicated are by '*', and are discussed in the text.

effect) predictor variable, and past tense accuracy (correct/incorrect) as the dependent variable. Neither verb imageability (over real verbs only; $B=0.05$, $t(84)=0.46$, $p=0.65$) nor the measure of phonological similarity ($B=0.003$, $t(84)=0.46$, $p=0.64$) predicted accuracy. Each of the remaining factors did independently predict accuracy, and thus were included as covariates in all HLM models reported below (sex: $B=-0.49$, $t(84)=1.74$, $p=0.08$; education: $B=0.13$, $t(84)=2.02$, $p=0.04$; WRAT-R: $B=0.04$, $t(84)=3.15$, $p=0.002$; WAIS-R FSIQ: $B=0.04$, $t(84)=4.11$, $p<0.0001$; past tense length: $B=-0.31$, $t(84)=4.36$, $p<0.0001$; consistent rime voicing: $B=-0.66$, $t(84)=3.08$, $p=0.003$). Note that because the two measures of IQ (WRAT-R and WAIS-R) were correlated ($r=0.54$, $p<0.0001$), and because both are ostensibly intended to capture the same group difference in general cognitive performance abilities, the two measures were included in separate models (see below). In no case did the choice of IQ measure substantially impact the pattern of results; below we report results from models containing WRAT-R scores (using the "best" imputation; see Table 1). Finally, item order (i.e., the order in which the item appeared in the presentation list) significantly predicted accuracy ($B=0.02$, $t(84)=7.81$, $p<0.0001$) and was included as a task-specific covariate in all HLM models below, to control for potential changes in subject performance over the course of the task.

We also examined several factors specific to the patients, again in separate logistic regression models. Examining diagnostic subtype (schizophrenia vs. schizoaffective disorder) showed that the patients diagnosed with schizoaffective disorder were slightly more accurate than those diagnosed with schizophrenia; producing a trend towards significance ($B=-0.80$; $t(42)=1.66$, $p=0.10$). This potential difference was not further investigated due to the small number of schizoaffective patients in our study. We also examined potential effects of medication on accuracy with two variables, neither of which predicted past-tense production accuracy: one contrasting first generation antipsychotic medications vs. other ($B=-0.90$; $t(42)=0.17$, $p=0.86$); and another contrasting second generation antipsychotic medications vs. other ($B=0.14$; $t(42)=0.33$, $p=0.74$). We also observed no effects on accuracy of either age of illness onset (first hospitalization; $B=-0.005$; $t(41)=0.14$, $p=0.89$) or illness duration ($B=-0.01$; $t(41)=0.47$, $p=0.64$).

2.5.2. Frequency effect analyses to examine potential compensation

To test for past-tense frequency effects we constructed an HLM model that included data from real verbs only from both patients and controls. The model included subject as a random effect, with past-tense frequency, subject group (patient, control), and verb type (regular, irregular) as fixed effects. Because this model did not converge with all six covariates included, we tested the subject-specific covariates (sex, WAIS-R FSIQ/WRAT-R reading, education) and the item-specific covariates (length, order, voicing consistency) in separate models. The results from the two models showed the same pattern of significance (i.e., the level of significance of all contrasts was identical in the two models (e.g., <0.0001, <0.01, <0.05, <0.10 and >0.10); here we report the statistics from the model including item-specific covariates).

2.5.3. Relation between past-tense accuracy and thought disorder

In order to test whether thought disorder may be related to grammatical and/or lexical performance, we examined the relations between thought disorder and performance on both verb types, for a subset of the data consisting only of those patients for whom TLC scores were available ($n=36$). This analysis was performed with an HLM model that included subject as a random effect, and TLC scores, verb type (regular, irregular), and the six covariates as fixed effects, with past tense accuracy as the dependent (binary) variable.

3. Results

3.1. Past tense accuracy

We examined performance (accuracy) in patients and controls for the past tense production task across the three different past tense types (Table 4). The 2 (group: patients, controls) × 3 (verb type: regulars, novels, irregular) interaction was significant ($F(2,84)=5.50$, $p=0.006$). In order to determine the origin of the significance of this interaction, we tested the 2 (group) × 2 (verb type) interactions for each of the three combinations of verb types. Both the group by regular/irregular interaction ($B=-0.66$; $t(84)=2.46$, $p=0.02$) and the group by novel/irregular interaction ($B=-0.81$; $t(84)=3.13$, $p=0.002$) were significant, whereas there was no group by regular/novel interaction ($B=0.14$; $t(84)=0.54$, $p=0.59$).

In order to determine whether this pattern of significant and non-significant interactions was driven by the (predicted) deficit of regulars and novels, or instead by a deficit of irregulars, we first examined the between-group differences separately for each verb type (including the six covariates). As expected, the patients performed significantly worse than controls on regulars ($B=-1.03$; $t(84)=2.91$, $p=0.005$) and novels ($B=-1.17$; $t(84)=3.41$, $p=0.001$), but were not worse than controls on irregulars ($B=-0.36$; $t(84)=1.05$, $p=0.30$). This suggests that the significant interactions are the result of a larger drop in performance in the patients (relative to controls) on regular and novel verbs than on irregular verbs.

Within-subject analyses (covarying out the six factors) further strengthened this conclusion. Whereas the controls performed better on regulars than irregulars ($B=0.67$; $t(84)=2.78$, $p=0.007$), the patients showed no significant difference ($B=-0.005$; $t(84)=0.03$, $p=0.98$), suggesting a relative decrement among the patients in performance on regulars as compared to irregulars. While the controls were less accurate at irregulars than novel verbs ($B=-0.52$; $t(84)=2.16$, $p=0.03$), the patients showed the opposite pattern, approaching statistical significance ($B=0.29$; $t(84)=1.59$, $p=0.12$). Whereas controls were equally good at novel and regular verbs ($B=0.15$; $t(84)=0.66$, $p=0.51$), the patients were better at regulars than novels ($B=0.30$; $t(84)=2.10$, $p=0.04$), consistent with the fact that, unlike novel past tenses, which have not been heard before, some regular past-tense forms may be memorized (e.g., high frequency past tenses; see Section 1).

Thus, after correcting for potentially confounding subject-, item- and task-specific factors, the results appear to support the hypothesis that the language profile of patients with schizophrenia involves deficient grammatical processing, with relatively spared lexical processing, at least for presumably early-learned lexical knowledge.

3.2. Errors at past tense production

Group differences ($ps \leq 0.10$ between patients and controls on both by-subjects and by-items t-tests) were observed on only two types of errors: unmarked forms and intrusions (Table 4). The patients made significantly more unmarked errors than did controls on both regular and novel verbs (*shrug-shrug, plag-plag*), but not on irregular verbs (*drive-drive*). The finding that unmarked errors were not made equally often on the three verb types suggests that these errors (which could be seen as just a repetition of the given stem) are not due to a lack of cooperation by the patients or a desire to not give an adequate response. Further, this suggests that such errors are not related to the morphosyntactic requirements of the task (i.e., processing the past-tense context of the sentences) which applied equally to all three verb types. Rather, the pattern is consistent with impairments of *-ed*-affixation and with previous findings from patients with grammatical/procedural deficits, such as those with Parkinson's disease or anterior aphasia, who are impaired at performance on regular past tenses (producing a large proportion of unmarked errors) (Ullman, in press; Ullman et al., 1997, 2005), and suggests similar deficits of grammatical rule processing in schizophrenia.

Intrusion errors showed the same pattern as unmarked errors, with the patients making significantly more such errors than did controls on regular and novel but not irregular verbs. Such a pattern further suggests a grammatical impairment, with relative lexical sparing. Also consistent with a grammatical deficit, many of the intrusion errors for regular and novel verbs were not past tense forms (even though all five intrusion errors for irregulars were past tenses), despite the fact that this was a past-tense production task: for regulars, fully 23% of the intrusion errors were stems (e.g., *scowl-scold*), with the rest either correctly formed regulars (69%; e.g., *cook-spilled*), or irregulars (8%; e.g., *slam-broke*). For novels, 25% were unmarked (e.g., *traf-adore*), with the remainder again either correct regular (58%; *satch-snatched*) or irregular (17%; *plag-rang*) past tenses.

But why would a grammatical impairment lead to intrusion errors rather than other errors? Oh, McCarthy, & McKenna (2002) suggested that intrusion errors in expressive speech (not just semantic associates but also unrelated words) may reflect a semantic deficit in schizophrenia, possibly related to the disorganization of lexical/semantic knowledge discussed in other studies. On the one hand, such a semantic deficit does not seem to fully explain the pattern of intrusion errors, since it would predict higher rates for patients than controls on both real regular and real irregular verbs (and possibly for novel verbs too, if the errors reflect an attempt to "make sense" of the novel input). On the other hand, such a deficit might help explain why intrusion errors (of which 7 of the 13 for regulars were semantic associates) rather than other errors were made, i.e., once the regular or novel inflected form failed to be computed.

3.3. Frequency effects and compensation

In both patients and controls, past tense frequency significantly predicted accuracy for irregular verbs (patients: $B = 0.49$; $t(84) = 8.15$, $p < 0.0001$; controls: $B = 0.29$, $t(84) = 4.12$, $p < 0.001$) but not for regular verbs (patients: $B = -0.04$; $t(84) = 0.83$, $p = 0.41$; controls: $B = -0.10$; $t(84) = 1.14$, $p = 0.26$). The magnitude of the frequency effects differed between regular and irregular verbs for both patients ($B = -0.53$; $t(84) = 6.78$, $p < 0.0001$) and controls ($B = -0.39$; $t(84) = 3.51$, $p < 0.001$). The group by verb type interaction on the effect of frequency was not significant ($B = -0.15$; $t(84) = 1.12$, $p = 0.27$). Thus it appears that the patients are not compensating for a deficit on regular past tense production by memorizing these forms. This finding is consistent with a dysfunction of learning in declarative memory post-disease onset in schizophrenia. (Note that these frequency effect results do not preclude the possibility that some regular past-tense forms might be stored in one or both groups.)

3.4. Thought disorder and past tense accuracy in schizophrenia

Thought disorder significantly predicted performance for regular ($B = -0.47$, $t(35) = 2.43$, $p = 0.02$) and novel ($B = -0.59$, $t(35) = 3.09$, $p = 0.004$) verbs, but not for irregulars ($B = -0.04$, $t(35) = 0.24$, $p = 0.81$). The effect of thought disorder on accuracy did not differ between regular and novel verbs ($B = 0.12$, $t(35) = 0.75$, $p = 0.46$), but did differ between regulars and irregulars ($B = -0.42$, $t(35) = 2.59$, $p = 0.01$) as well as between novel and irregular verbs ($B = 0.54$, $t(35) = 3.37$, $p = 0.002$).

4. Discussion

Patients with schizophrenia showed a greater deficit, relative to healthy control subjects, at producing the past tenses of regular and novel verbs than of irregular verbs. A wide range of factors were controlled for, and thus are unlikely to explain the observed results: subject-specific factors (sex, handedness, age, years of education, and pre- and post-morbid IQ), item-specific factors (past-tense frequency, past-tense phonological length, verb imageability, phonological neighborhood, consistent rhyme voicing), and one task-specific factor (item order).

The pattern of results appears to support the dual-system hypothesis that the language profile of patients with schizophrenia involves deficient grammatical processing with relatively spared processing of (early-learned) lexical knowledge. Additionally, the patients with schizophrenia made more unmarked errors than healthy adults at regular and novel verbs (*shrug-shrug*, *plag-plag*) but not irregular verbs (*drive-drive*), consistent with previous findings from patients with grammatical/procedural deficits (Parkinson's disease; anterior aphasia) (Ullman, in press; Ullman et al., 1997, 2005). Similarly, the patients made more intrusion errors on regular and novel (*scowl-scold, traff-door*) than irregular (*dig-conquered*) verbs.

A grammatical deficit in schizophrenia is also consistent with prior evidence. First, numerous studies have suggested syntactic impairments in schizophrenia (see Covington et al., 2005; DeLisi, 2001). Second, neuroanatomical evidence suggests a frontal/basal-ganglia dysfunction in the disorder, consistent with independent evidence linking frontal/basal-ganglia circuits to the mental grammar (Ullman, 2008; Ullman et al., 2005).

It may seem somewhat surprising that the patients would show a deficit at regulars. They should have had ample opportunity to compensate for a grammatical deficit by simply memorizing regular past-tense forms, given that they had several years to memorize these forms post-disease onset (mean 13 years of illness duration; Table 1). However, as we have seen above, learning in declarative memory seems to be impaired in schizophrenia. Indeed, the frequency effect analyses suggest that the patients are not retrieving regular past tenses from memory, and thus that they are not compensating by memorizing these forms.

The relationship between thought disorder and accuracy at producing regular and novel but not irregular past-tense forms suggests that thought disorder may be somehow related to a grammatical impairment. The pattern of intrusion errors, which have been linked to thought disorder (Oh et al., 2002), and were also found on regular and novel but not irregular verbs, may also be consistent with this view. The results appear to be inconsistent with claims that thought disorder reflects a general cognitive dysfunction (see Section 1), since any general dysfunction seems unlikely to affect regular and novel verbs differently from irregular verbs, particularly given the factors controlled for in the present study.

4.1. Alternative models of the neurocognition of language

"Single-mechanism" models of the neurocognition of language posit that the learning and use of language depend on a single computational mechanism, and so assume no a priori distinction between lexicon and grammar (Joanisse & Seidenberg, 1999; Rumelhart & McClelland, 1986). One such model hypothesizes that the computation of irregular inflected forms depends particularly on semantics (in comparison to regular verbs), while inflection of novel forms depends particularly on phonology (Joanisse & Seidenberg, 1999). Simulations of phonological damage to the model revealed a pattern of greater impairment on the production of past-tense forms for novel verbs than for regular and irregular verbs (which in turn were similarly impaired) (Joanisse & Seidenberg, 1999).

At first blush, these simulation results appear similar to the accuracy pattern observed for patients in the present study: contrasts between verb types within the patients revealed that they performed worst at novel past tense production, with no difference between regulars and irregulars. On a single-mechanism view, our results might therefore be interpretable as reflecting a phonological deficit in schizophrenia. Indeed, phonological deficits in schizophrenia have been reported (e.g., Angrilli et al., 2009; Crow, Done, & Sacker, 1995).

However, this interpretation is inconsistent with the interactions between verb type and participant group, which more clearly indicate a similar deficit on novels and regulars (relative to healthy controls) that is in both cases worse than the deficit on irregulars. Note that in the simulation study, comparable interactions were not examined (Joanisse & Seidenberg, 1999). Moreover, a number of phonological variables were controlled for in our analyses (see Section 2 and Table 3), suggesting that the observed pattern may not be due to phonological factors (e.g., see Bird, Lambon Ralph, et al., 2003).

4.2. Limitations of the current study

One important limitation of our findings pertains to the effects of antipsychotic medication, as prior results have shown an effect of antipsychotic treatment on basal-ganglia structure and function (e.g., Goldman et al., 2008). While the majority of patients in this study were receiving antipsychotics, we did not have a large enough number of unmedicated patients to determine the effects of medication. In addition, the heterogeneous nature of schizophrenia may limit the generalizability of our findings. That is, it is not clear whether the results reflected the same impairment across all patient subgroups, or were primarily due to only certain subgroups. Patients in this study were also not selected with respect to the presence or absence of formal thought disorder, so our findings that suggest a link between thought disorder and grammar could be followed up on with patient groups selected and categorized on this basis (Oh et al., 2002). Finally, while we have made some inferences regarding neuroanatomy, direct examination of the brain substrates underlying the language functions examined here would add important evidence, and should be included in future studies.

5. Summary and conclusion

Patients with schizophrenia were worse at producing the past tenses of regular and novel than irregular verbs, as compared to healthy control subjects. This pattern, which was not due to a variety of potentially confounding factors, supports the dual-system hypothesis that grammatical processing is impaired in schizophrenia, while lexical processing remains relatively spared, at least for forms like irregulars which are presumably learned well before disease onset. Additionally, patients' thought-disorder scores predicted their performance at regular and novel (but not irregular) past-tense production, consistent with previous findings suggesting a relationship between thought disorder and grammar. In sum, this study sheds light on the nature of language deficits in schizophrenia, and provides additional evidence regarding the neurocognitive basis of language.

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