

## Speeded processing of grammar and tool knowledge in Tourette's syndrome

Matthew Walenski<sup>a</sup>, Stewart H. Mostofsky<sup>b,c</sup>, Michael T. Ullman<sup>a,\*</sup>

<sup>a</sup> Brain and Language Lab, Department of Neuroscience, Georgetown University, Washington, DC 20057-1464, United States

<sup>b</sup> Kennedy Krieger Institute, United States

<sup>c</sup> Departments of Neurology and Psychiatry, Johns Hopkins University School of Medicine, United States

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### Abstract

Tourette's syndrome (TS) is a developmental disorder characterized by motor and verbal tics. The tics, which are fast and involuntary, result from frontal/basal-ganglia abnormalities that lead to unsuppressed behaviors. Language has not been carefully examined in TS. We tested the processing of two basic aspects of language: idiosyncratic and rule-governed linguistic knowledge. Evidence suggests that idiosyncratic knowledge (e.g., in irregular past tense formation; *bring–brought*) is stored in a mental lexicon that depends on the temporal-lobe-based declarative memory system that also underlies conceptual knowledge. In contrast, evidence suggests that rule-governed combination (e.g., in regular past tenses; *walk + -ed*) takes place in a mental grammar that relies on the frontal/basal-ganglia-based procedural memory system, which also underlies motor skills such as how to use a hammer. We found that TS children were significantly faster than typically developing control children in producing rule-governed past tenses (*slip–slipped*, *plim–plimmed*, *bring–bringed*) but not irregular and other unpredictable past tenses (*bring–brought*, *splim–splam*). They were also faster than controls in naming pictures of manipulated (*hammer*) but not non-manipulated (*elephant*) items. These data were not explained by a wide range of potentially confounding subject- and item-level factors. The results suggest that the processing of procedurally based knowledge, both of grammar and of manipulated objects, is particularly speeded in TS. The frontal/basal-ganglia abnormalities may thus lead not only to tics, but also to a wider range of rapid behaviors, including the cognitive processing of rule-governed forms in language and other types of procedural knowledge.

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Tourette's syndrome (TS) is a developmental disorder characterized by the presence of verbal and motor tics (APA, 1994). Tics, which may be expressed as “simple” or “complex” motor movements or vocalizations (e.g., “simple” grunting, or “complex” shouting of phrases), are both fast and involuntary (see references below and Tullen, Groeneveld, Romers, De Vries, & Van De Wetering, 2001). The tics appear to be caused by disturbances of the basal ganglia and closely connected regions of cortex, especially motor and cognitive regions of the frontal lobes (Albin & Mink, 2006; Albin, Young, & Penney, 1989; Bradshaw, 2001; Singer & Wendlandt, 2001). Such disturbances

are reflected in structural abnormalities of the basal ganglia and frontal cortex (Fredericksen et al., 2002; Kates et al., 2002; Ludolph et al., 2006) and in abnormal levels of dopamine, a crucial neurotransmitter crucial in frontal/basal-ganglia circuits (for review and discussion, see Albin, 2006; Kienast & Heinz, 2006; Mink, 2006; Rauch & Savage, 1997; Singer & Wendlandt, 2001). The frontal/basal-ganglia abnormalities are thought to result in decreased inhibition of frontal activity, leading to a hyperkinetic behavioral profile and an inability to suppress tics (Albin & Mink, 2006; Osmon & Smerz, 2005).

Language in Tourette's syndrome has not been thoroughly examined. Whereas much attention has been focused on vocal tics (Frank, 1978; Gates et al., 2004; Goldenburg, Brown, & Weiner, 1994; Lang, Consky, & Sandor, 1993; Martindale, 1976; Peterson et al., 1998; Serra-Mestres, Robertson, & Shetty, 1998; Singer, 1997; Van Borsel & Vanryckeghem, 2000; Woods, Watson, Wolfe, Twohig, & Friman, 2001), few studies have

\* Corresponding author at: Brain and Language Lab, Department of Neuroscience, Georgetown University, Box 571464, Washington, DC 20057-1464, United States. Tel.: +1 202 687 6064; fax: +1 202 687 6914.

E-mail address: michael@georgetown.edu (M.T. Ullman).

investigated non-tic-related language. Moreover, these few studies have relied on standard neuropsychological measures and clinical impressions (Brookshire, Butler, Ewing-Cobbs, & Fletcher, 1994; Legg, Penn, Temlett, & Sonnenberg, 2005; Ludlow, Polinsky, Caine, Bassich, & Ebert, 1982; O'Quinn & Thompson, 1980; Scheurholz, Baumgardner, Singer, Reiss, & Denckla, 1996). While they have reported some abnormalities, particularly in expressive language, a comprehensive profile of language in the disorder is still lacking (Legg et al., 2005).

Here we attempt to extend our understanding of the language profile in Tourette's syndrome by examining two basic aspects of language: idiosyncratic and rule-governed knowledge. Idiosyncratic knowledge includes all arbitrary sound-meaning associations (e.g., /kæt/refers to the small furry feline) and word-specific morphological and syntactic information (e.g., *spring* takes *sprang* as its irregular past tense form). Rule-governed knowledge, in contrast, underlies the combination of words and parts of words into complex words (e.g., in regular past tenses, such as *walk* + *-ed*), phrases and sentences (Pinker, 1999; Pinker & Ullman, 2002).

According to "dual-system" models (see Section 3 for single-mechanism models), all idiosyncratic linguistic knowledge, such as of sound-meaning associations and irregular morphophonology (e.g., *spring*–*sprang*), is stored in the mental lexicon (Pinker, 1999; Pinker & Ullman, 2002; Ullman, 2001a, 2001b). The lexicon depends on an associative memory that can generalize patterns from already stored forms to new ones (e.g., from *sing*–*sang*, *spring*–*sprang*, *ring*–*rang* to the novel irregular past tense *spling*–*splang*). Thus, unlike a rote memory, this memory system is productive, though the extent of its productivity remains unclear. In contrast, rule-governed complex forms, such as real and novel regular past tenses, are generally computed by the mental grammar (e.g., *walk* + *-ed*, *blick* + *-ed*). This grammatical combination is a default process and applies to any form for which the associative memory system cannot produce an acceptable output. Thus failure to retrieve the memorized form *sprang* could result in the over-regularization error *springed*, while failure to associatively generalize *spling* to a novel form such as *splang* could result in the novel regularization *splinged*.

However, not all regular or other apparently rule-governed forms are predicted to be computed by the grammar (Hartshorne & Ullman, 2006; Pinker, 1999; Pinker & Ullman, 2002; Prado & Ullman, submitted for publication; Ullman, 2001a, in press-c). Of interest here, the past tenses of regular verbs whose stems are phonologically similar to those of irregular verbs (e.g., *glide*–*glided*) are predicted to be stored in memory rather than composed by the mental grammar; storage of these "inconsistent" regular past tense forms prevents their irregularization, e.g., *glide*–*glode* or *glide*–*glid*, cf. *ride*–*rode* or *hide*–*hid* (Ullman, 1993, 2001a; Ullman, Maloof et al., submitted for publication). Thus both irregular and inconsistent regular inflected forms are expected to be stored in the lexicon, while "consistent" regulars, whose stems are *not* phonologically similar to the stems of irregulars (e.g., *walked*), are predicted to be generally composed by the mental grammar.

Evidence has linked the mental lexicon (including irregular inflected forms) and the mental grammar (including consistent

regular inflected forms) to distinct neurocognitive systems, each of which is known to subserve non-language functions. Specifically, evidence suggests that lexical memory depends on the declarative memory system, whereas the mental grammar relies on the procedural memory system (Ullman, 2001b, 2004, 2005, 2006a, in press-c; Ullman et al., 1997).

These two memory systems have different characteristics and depend on largely distinct neurobiological substrates. Declarative memory subserves the learning, representation, and use of knowledge about facts and events, such as the fact that elephants live in Africa, or that you had pumpkin ravioli for dinner last night (Eichenbaum, 2001; Eichenbaum & Cohen, 2001; Mishkin, Malamut, & Bachevalier, 1984; Squire & Knowlton, 2000; Squire, Stark, & Clark, 2004). The system seems to be specialized for learning arbitrary pieces of information and the associations between them (Eichenbaum, 2001; Eichenbaum & Cohen, 2001; Poldrack & Rodriguez, 2003). The learned knowledge is at least partly (but not completely; Chun, 2000) explicit—that is, available to conscious awareness. The hippocampus and other medial temporal structures consolidate and retrieve new memories, which eventually come to depend largely on neocortical regions, particularly in the temporal lobes (Eichenbaum & Cohen, 2001; Hodges & Patterson, 1997; Martin, Ungerleider, & Haxby, 2000; Squire et al., 2004). Other brain structures also play a role in declarative memory, including Brodmann's areas (BA) 45/47 in inferior frontal cortex, which underlies the selection or retrieval of declarative memories (Ullman, 2006b). Declarative memory and hippocampal function can be enhanced by estrogen (McEwen, Alves, Bulloch, & Weiland, 1998; Resnick, Maki, Golski, Kraut, & Zonderman, 1998; Sherwin, 1988), perhaps via the modulation of acetylcholine (Packard, 1998) and/or BDNF (brain-derived neurotrophic factor) (Scharfman & MacLusky, 2005), both of which play important roles in declarative memory independent of estrogen (Egan et al., 2003; Freo, Pizzolato, Dam, Ori, & Battistin, 2002; Hariri et al., 2003; Pezawas et al., 2004).

The procedural memory system underlies the gradual implicit (non-conscious) learning of new, and control of long-established, motor and cognitive 'skills' and 'habits', especially those involving rules or sequences, such as riding a bicycle and using tools and other manipulated objects (Mishkin et al., 1984; Poldrack & Packard, 2003; Squire & Knowlton, 2000; Ullman, 2004; Willingham, 1998). This system, which is composed of a network of brain structures, is rooted in frontal/basal-ganglia circuits, in particular the caudate nucleus within the basal ganglia, and premotor regions and BA 44 within frontal cortex. It also encompasses other structures, including portions of superior temporal cortex and the cerebellum (Ullman, 2004). The neurotransmitter dopamine plays a particularly important role in procedural learning (Goerendt et al., 2003; Harrington, Haaland, Yeo, & Marder, 1990; Nakahara, Doya, & Hikosaka, 2001). Note that the term "procedural memory" is used here to refer *only* to one type of implicit, non-declarative, memory system (Squire & Zola, 1996), *not* to all such systems. Additionally, both the declarative and procedural memory systems refer here to the *entire* systems involved in the learning and use of the relevant knowledge or skills (Eichenbaum, 2000), not

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