The memorization of complex forms in aphasia: Implications for recovery

John E. Drury and Michael T. Ullman*

Department of Neuroscience, Georgetown University, Washington, DC 20007, USA

Agrammatic non-fluent aphasics with frontal lesions ("anterior aphasics;" e.g., Broca's aphasics) are worse at generating, reading out loud, repeating, writing, and judging regular than irregular inflected forms. Fluent aphasics with temporal/temporo-parietal lesions ("posterior aphasics;" e.g., Wernicke's aphasics) show the opposite pattern (Ullman, 2001). This and other evidence suggest that the memorization and use of idiosyncratic word-specific knowledge, including irregular past-tense representations (*dug*), are subserved by temporal-lobe circuits, whereas the composition of predictably structured complex linguistic representations, including regular past-tenses (*walk + -ed*), relies on left frontal-lobe structures (Ullman, 2001).

If anterior aphasics retain the ability to memorize and retrieve lexical forms, they might store complex forms (*walked*) that cognitively unimpaired subjects and posterior aphasics compose on-line (*walk + -ed*). Thus, recovery of function in anterior aphasia might at least partly entail a shift of reliance from the frontal-lobe system that composes to the temporal-lobe system that memorizes. This should be detectable by a variety of methods.

Here, we examine these predictions by testing for the memorization of regular and irregular past-tense forms with surface-frequency and phonological-neighborhood effects. Stored words are remembered better and faster if they have been more frequently encountered. Such "frequency effects" are expected for representations stored in the lexicon, but not for representations that are composed in real-time. Several studies report frequency effects for irregular but not regular past-tenses. This suggests that representations of irregular but not regular past-tenses are retrieved from memory. Intriguingly, frequency effects for some types of regulars (e.g., high-frequency forms) suggest that regular forms *can* be stored (Pinker, 1999; Ullman, 2001).

Similar inferences about storage versus real-time composition arise from the presence/absence of phonological-neighborhood effects. If multiple stored representations share distributed memory traces (*sing-sang*, *spring-sprang*, and *ring-rang*), then strengthening one representation should strengthen all of them. Such neighborhood frequency effects have been found for irregulars but not regulars (Pinker, 1999; Ullman, 2001), suggesting that generally only irregulars are represented in an associative lexical memory.

If frequency and neighborhood effects diagnose the storage of past-tense forms, both anterior and posterior aphasics should show these effects for irregular past-tenses; only anterior aphasics should show them for regular past-tense forms, if only these aphasics memorize regular past-tenses following injury.

Methods. Subjects comprised nine agrammatic non-fluent aphasics with (at least) frontal-lobe damage and five fluent aphasics with (at least) temporal-lobe damage. All subjects were monolingual native speakers of English, right-handed before le-

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

sion-onset. Items consisted of 17 regular and 17 irregular monosyllabic past-tense forms, matched pairwise on stem and past-tense frequency and on phonological complexity (Ullman et al., in press). Subjects were presented with these forms in isolation (not in sentence contexts) in a pseudo-randomized order and instructed to read them aloud. Accuracy (correct/incorrect) of first response constituted the dependent measure. This task yields worse performance at regular than irregular past-tense forms in anterior aphasia and the opposite pattern in posterior aphasia, suggesting that the task invokes the two language brain systems (Ullman et al., in press).

Surface-frequency for each past-tense item was calculated by summing the raw frequency counts of identical past-tense and past-participial forms, from both the Brown and Associated Press corpora, and then *ln*-transforming this quantify after augmenting it by 1 to avoid *ln* (0) (Ullman et al., in press). This past-tense/past-participle combined measure should predict the accuracy of isolated inflected forms read aloud; however, past-tense frequency alone yielded a similar pattern of results as those described below.

Phonological neighborhood measures were calculated as follows. For each irregular item (e.g., *sprang*), for all of its neighbors (same spelling and phonology in the rhyme of the verb stem), the cumulative past-tense/past-participle token frequency of all irregular enemies (*bring-brought*, etc.) was subtracted from that of all irregular friends (*sing-sang*, etc.), yielding a raw token-count that was either positive (friendly), negative (hostile), or zero (neutral). Regular enemies (*wing-winged*) were excluded from irregular neighborhoods because we predicted that they should have a much lower likelihood of memorization than the irregulars—even in anterior aphasics, they should most likely be memorized only after lesion-onset—and therefore they would be unlikely to influence a given irregular as much as other irregulars (as expected, a neighborhood count *including* regular enemies did *not* predict patient performance). For the calculation of regular forms' neighborhoods, regulars counted as friends; irregulars with phonologically similar stems were included as enemies (e.g., *show-showed*: *grow-grew*, etc.) because the irregulars' ubiquitous memorization predicts strong influence on their part. The absolute values of the raw sums were *ln*-transformed after being augmented by 1. Finally, the *ln*- transformed values that corresponded to negative raw counts (hostile neighborhoods) were multiplied by −1.

Results and discussion. As predicted, the surface-frequency and neighborhood measures correlated with accuracy of irregular past-tenses (averaged over subjects) in both the anterior and posterior aphasics, but with accuracy of regular past-tenses in only the anterior aphasics (see Table 1). The same pattern of results was obtained with individual-subject analyses. These results suggest that irregular past-tense representations were retrieved from memory by both subject groups, whereas only anterior aphasics retrieved regular past-tense representations. Given that the frequency/neighborhood effects were not observed for regulars among the posterior aphasics, and are not typically found in cognitively unimpaired subjects, these data suggest that the anterior aphasics memorized regular past-tense forms after lesion-onset. The plausibility of such a shift from the on-line composition of complex representations to their

Table 1
Frequency and phonological neighborhood effects

	Measure	Anterior		Posterior	
		Pearson's R	p	Pearson's R	p
Regulars	Surface frequency	0.54	<0.01	0.18	0.26
	Neighborhood strength	0.62	<0.01	0.19	0.46
Irregulars	Surface frequency	0.42	<0.05	0.43	<0.05
	Neighborhood strength	0.51	<0.05	0.69	<0.01

memorization is demonstrated by similar shifts in other populations with putative dysfunctional frontal/grammatical system, as demonstrated by frequency effects and other methods (Ullman, 2001). Finally, the data presented here have implications for therapeutic approaches for the recovery of language.

References

Pinker, S. (1999). *Words and rules: The ingredients of language*. New York: Basic Books.
Ullman, M. T. (2001). A neurocognitive perspective on language: The declarative/procedural model. *Nature Reviews Neuroscience, 2*, 717–726.
Ullman, M. T., Izvorski, R., Love, T., Yee, E., Swinney, D., & Hickok, G. (in press). Neural correlates of lexicon and grammar: Evidence from the production, reading, and judgment of inflection in aphasia. *Brain and Language*.

Sex differences in the neurocognition of language

Michael T. Ullman,[a,*] Ivy V. Estabrooke,[a,b] Karsten Steinhauer,[a] Claudia Brovetto,[a] Roumyana Pancheva,[a,c] Kaori Ozawa,[a] Kristen Mordecai,[d] and Pauline Maki[d]

[a] *Departments of Neuroscience and Linguistics, Georgetown University, Washington, DC, USA*
[b] *Interdisciplinary Program in Neuroscience, Georgetown University, Washington, DC, USA*
[c] *Departments of Linguistics and Slavic, University of Southern California, Los Angeles, CA, USA*
[d] *National Institute of Aging, Baltimore, MD, USA*

We have argued, based on several lines of evidence, that language processing depends upon two neurocognitive systems (Ullman, 2001). The mental lexicon, which contains (at least) idiosyncratic word-specific information (e.g., for irregular past-tenses; *break-broke*), depends on the temporal-lobe-based declarative memory system. Aspects of the mental grammar underlying the real-time rule-based composition of complex linguistic representations (e.g., regular past-tenses; *play + -ed*) depend on a frontal/basal-ganglia procedural system that also subserves motor skills.

Females are better than males at remembering words (Kimura, 1999). We posited a sex difference in the processing of complex linguistic representations: females may tend to memorize previously encountered complex representations (e.g., regular past-tenses; *played*) that males generally compose on-line (*play + -ed*). Both sexes should memorize idiosyncratic lexical knowledge (*break-broke*); and both should rule-compute new complex forms (*proy + -ed*), because these could not be memorized. We have obtained converging evidence for these predictions from five studies:

[*] Corresponding author.
E-mail address: michael@georgetown.edu (M.T. Ullman).