TITLE: Acquisition and generalization responses in aphasia treatment: Evidence from sentence-production treatment

INTRODUCTION

Treatment of Underlying Forms (TUF) promotes not only acquisition of treated sentence types but also generalization to related but untreated sentences (e.g., Thompson, Shapiro, Kiran & Sobecks, 2003). In a meta-analysis examining TUF treatment outcomes, Dickey and Yoo (2010) found evidence that the factors governing TUF acquisition and generalization may be different. They found that general auditory comprehension ability but not overall aphasia severity or sentence-comprehension impairment predicted participants' acquisition of treated sentences. In contrast, none of these factors were related to participants' generalization to related but untreated sentences. Interestingly, Meinzer and colleagues (2010) found similar results for naming treatment: brain areas that were positively related to acquiring treated items were not associated with generalization to untreated words.

These findings suggest that the mechanisms responsible for acquisition and generalization responses to aphasia treatment may be distinct. The current study examined this question further by testing the dose-response relationships for TUF, for both acquisition and generalization. It analyzed existing TUF treatment studies by using multilevel generalized linear regression to model changes in probe accuracy over the course of treatment. One model estimated the slope and intercept of acquisition and generalization curves in response to increasing amounts of treatment. A second set of models tested whether these dose-response relationships were moderated by aphasia severity (viz. Dickey & Yoo, 2010).

Determining whether acquisition and generalization curves exhibit similar slopes and intercepts, and whether they are moderated by the same factors, will help establish how similar the two treatment responses are. Comparing the slopes and intercepts of these curves can also shed light on whether similar amounts of treatment are needed to promote acquisition and generalization.

METHOD

Fourteen treatment studies published through 2007 involving TUF were identified. All studies involved single-subject, multiple-baseline or single-participant case studies. Seven of the fourteen studies reported individual probe accuracy data for each treatment session, as well the number of trials per probe for each structure being tested (Table 1). These included data from 29 adults with aphasia.

Data: Individual probe accuracy data (the number of successes and failures for each probe) were extracted for each participant and treatment session, based on published tables or figures. Probe accuracy data for acquisition stimuli and generalization targets were coded separately for each treatment phase. Probe accuracy for the sentence type being treated during a given treatment phase (e.g., object clefts) was treated as a measure of acquisition. Probe accuracy for related but untreated sentences (e.g., object wh- questions) was treated as a measure of generalization. Data for unrelated sentence types (e.g., passives) as well related but more complex sentence types (e.g., object relative clauses) were treated as control data, since generalization is not expected to such sentence types (Thompson, et al., 2003). If an individual underwent multiple treatment phases during a study, only data for the first phase were analyzed.

Aphasia severity, which has previously been shown to be relevant for treatment response (Robey, 1998), was also extracted for analysis as a person-level predictor. WAB AQ (Kertesz, 1982) was available for 23 participants (mean=65, sd=9, range=48-85).

Statistical analysis: The data were analyzed using multilevel generalized linear regression with a logistic-binomial link function. Multilevel regression better accounts for within-subject and within-study dependencies than single-level regression, and logistic-binomial functions are more appropriate for proportion data than linear functions. Models were built in forward stepwise fashion, using the Akaike information criterion to evaluate whether each additional effect improved model fit.

The first model tested for differences in acquisition, generalization, and control curves as a function of amount of treatment. It treated the number of treatment sessions (probe number) and stimulus type (acquisition, generalization, control) as fixed effects. Probe number was coded starting at 0 for each subject, so that the intercept could be directly interpreted as the log odds of a correct response at the first treatment probe. Subject, syntactic structure, and study were treated as random effects.

The second set of models tested the effect of aphasia severity on the treatment response curves. Separate models were built for acquisition, generalization, and control curves because the omnibus model did not converge. We examined the fit of each final model using residual plots.

RESULTS

For the first analysis, the final model included statistically significant ($p<0.05$) fixed effects for probe number, stimulus type contrast (acquisition vs. generalization, acquisition vs. control), and the probe number-by-stimulus type interaction for acquisition vs. control stimuli. The model also included a random intercept for the subject-by-syntactic structure interaction, random effects of probe number for both subjects-by-structure and study, and a random effect of stimulus type for subjects-by-structure. See Table 2 for model coefficients and random effects, and Figure 1 for a plot of fixed effects.

For the second analysis, the initial model for acquisition data included a significant fixed effect of probe number, as well as a random intercept for the subject-by-structure interaction, and random effects of probe number for subject-by-structure and study. The initial models for the generalization and control data were similar, but lacked the random effect of probe number for study. WAB AQ and the WAB AQ-by-probe number interaction were then entered into each model. The WAB AQ-by-probe number interaction was positive and significant for both acquisition and generalization models. The interaction was not a significant predictor in the control model, and the main effect for WAB AQ was non-significant in all three models. See Tables 3-5 for model coefficients and random effects, and Figure 3 for fixed effects for acquisition and generalization.

Residual plots revealed poor model fit for some subjects, most often due to due to rapid transitions from poor to excellent performance, or to occasional poor performance following multiple observations of good performance.

DISCUSSION

The patterns of treatment response for acquisition and generalization in response to TUF are qualitatively similar, though shifted in time, with the generalization response emerging slightly later and having a similar but marginally lower ($p=.08$) slope. By contrast, control stimuli showed the expected minimal treatment response, with essentially no positive slope over time.

Acquisition and generalization responses were also similarly moderated by aphasia severity, with milder aphasia being associated with faster treatment response for both types of stimuli. Aphasia severity did not influence control stimuli.

These findings contrast with those of Dickey and Yoo (2013), who found that acquisition and generalization exhibited qualitatively different treatment response curves in a single-level linear regression. They also refine the conclusion of Dickey and Yoo (2010) that TUF treatment response, as indexed by effect size, is not predicted by aphasia severity. These differences may be due to the nonlinear multilevel analyses used in the current study.

In contrast to recent work (Dickey & Yoo, 2010, Meinzer et al, 2010), these findings indicate that the two types of treatment response for TUF – acquisition and generalization – are similar. Apparent differences in treatment response for acquisition versus generalization previously observed may be due to the non-linear nature of the treatment response mechanism. At the same time, these findings suggest that different amounts of treatment are required to promote acquisition and generalization. Improvements for generalization targets emerge later than for acquisition stimuli, particularly for more severely impaired participants. TUF treatment may therefore need to be extended for some individuals to increase the likelihood of generalization.

REFERENCES

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Table 1. Treatment studies included in the present analyses.

	Treatment study	**Number of participants**
1	Thompson, C.K., Shapiro, L.P., Kiran, S., & Sobecks, J. (2003) The role of syntactic complexity in treatment of sentence deficits in agrammatic aphasia: The complexity account of treatment efficacy (CATE). *Journal of Speech, Language, and Hearing Research*. 46: 591-607.	4
2	Ballard, K. J. & Thompson, C. K. (1999). Treatment and generalization of complex sentence production in agrammatism. *Journal of Speech, Language, and Hearing Research, 42*, 690-707.	5
3	Thompson, C. K., Shapiro, L. P., Tait, M. E., Jacobs, B. J., & Schneider, S. S. (1996). Training wh-question production in agrammatic aphasia: Analysis of argument and adjunct movement. *Brain and Language, 52*, 175-228.	7
4	Jacobs, B. J. & Thompson, C. K. (2000). Cross-modal generalization effects of training noncanonical sentence comprehension and production in agrammatic aphasia. *Journal of Speech, Language, and Hearing Research*, 43, 5-20.	4
5	Murray, L., Timberlake, A., & Eberle, R. (2007). Treatment of Underlying Forms in a discourse context. *Aphasiology*, 21, 139–163.	1
6	Wambaugh, J. L., & Thompson, C. K. (1989). Training and generalization of agrammatic aphasic adults' *wh*interrogative productions. *Journal of Speech and Hearing Disorders, 54*, 509–525.	4
7	Murray, L. L., Ballard, K., & Karcher, L. (2004). Linguistic Specific Treatment: Just for Broca's aphasia? *Aphasiology*, 18, 785-809.	4

Table 2. Binomial logistic model coefficients and random effects for the analysis of treatment response curves by stimulus type (acquisition, generalization, control).

Fixed Effects	Estimate	Std. Error	z-value	p-value
Intercept	2.60	0.35	-7.48	<0.0001
Probe Number	0.86	0.25	3.51	0.0004
Stimulus Type (Generalization vs. Acquisition)	-1.06	0.36	-2.98	<0.0001
Stimulus Type (Control vs. Acquisition)	-3.43	0.61	-5.66	0.0029
Stimulus Type (Generalization vs. Acquisition) by Probe Number	-0.05	0.03	-1.75	0.08
Stimulus Type (Control vs. Acquisition) by Probe Number	-0.85	0.13	-6.32	< 0.0001

Random Effects Group	Effect	Std. Dev.
Subject-by-Syntactic Structure	Intercept	2.26
	Probe	0.50
	Stimulus Type (Generalization)	1.65
	Stimulus Type (Control)	4.23
Study	Probe	0.37

Table 3. Binomial logistic model coefficients and random effects for the effect of aphasia severity (measured by WAB AQ) on acquisition treatment response.

Fixed Effects	Estimate	Std. Error	z-value	p-value
Intercept	-2.16	0.35	-6.20	<0.0001
Probe Number	1.00	0.39	2.54	0.01
WAB AQ	0.003	0.03	0.09	0.93
WAB AQ by Probe Number	0.03	0.01	3.31	0.0009
Random Effects				
Group	Effect	Std. Dev.		
Subject-by-Syntactic Structure	Intercept	1.61		
	Probe	0.27		
Study	Probe	0.93		

Table 4. Binomial logistic model coefficients and random effects for the effect of aphasia severity (measured by WAB AQ) on generalization treatment response.

Fixed Effects	Estimate	Std. Error	z-value	p-value
Intercept	-3.62	0.62	-5.77	<0.0001
Probe Number	0.56	0.12	4.77	<0.0001
WAB AQ	-0.06	0.07	-0.90	0.37
WAB AQ by Probe Number	0.05	0.01	3.38	0.0007
Random Effects				
Group	Effect	Std. Dev.		
Subject-by-Syntactic Structure	Intercept	3.25		
	Probe	0.60		

Table 5. Binomial logistic model coefficients and random effects for the effect of aphasia severity (measured by WAB AQ) on treatment response to control probes.

Fixed Effects	Estimate	Std. Error	z-value	p-value
Intercept	-5.82	0.44	-13.2	<0.0001
Probe Number	-0.02	0.04	-0.41	0.68
WAB AQ	0.05	0.04	1.22	0.22
WAB AQ by Probe Number	0.003	0.005	0.62	0.54
Random Effects				
Group	Effect	Std. Dev.		
Subject-by-Syntactic Structure	Intercept	2.33		
	Probe	0.11		

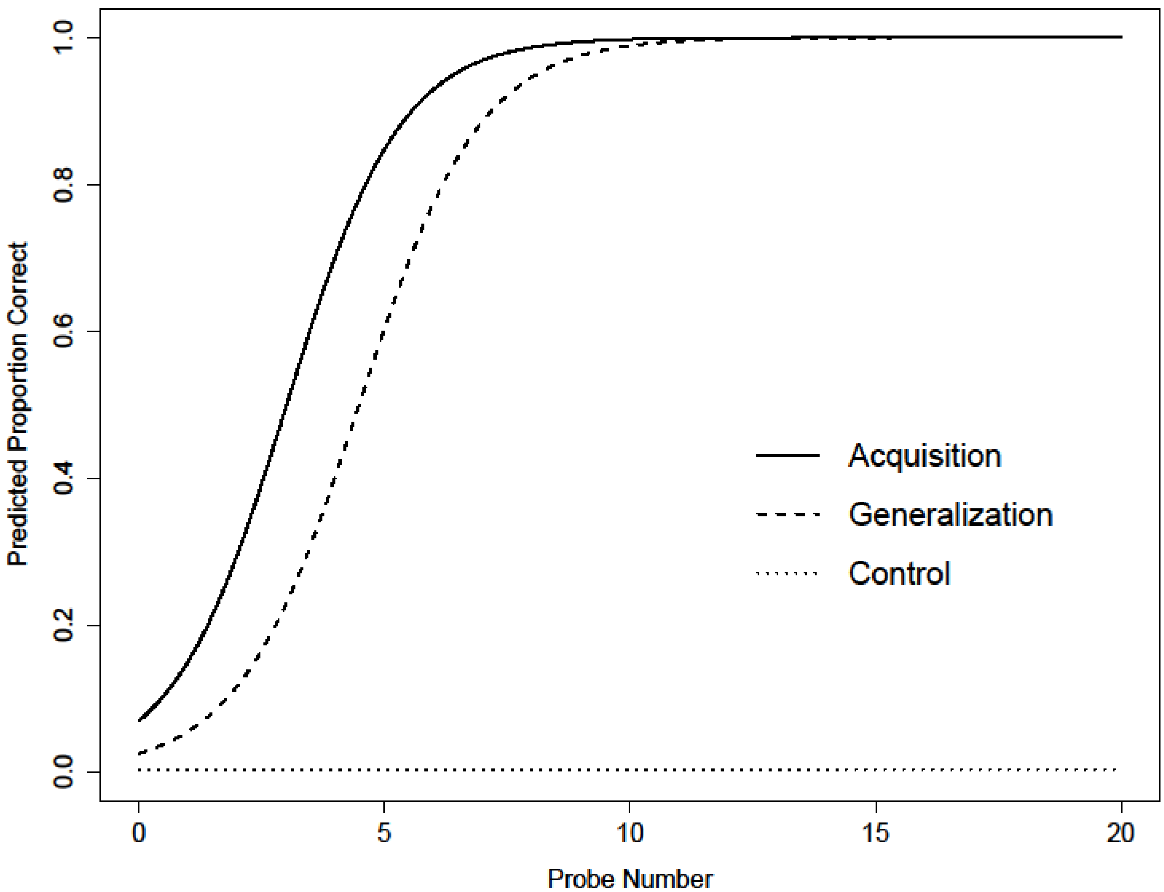

Figure 1. Plots of model-predicted treatment response curves by stimulus type.

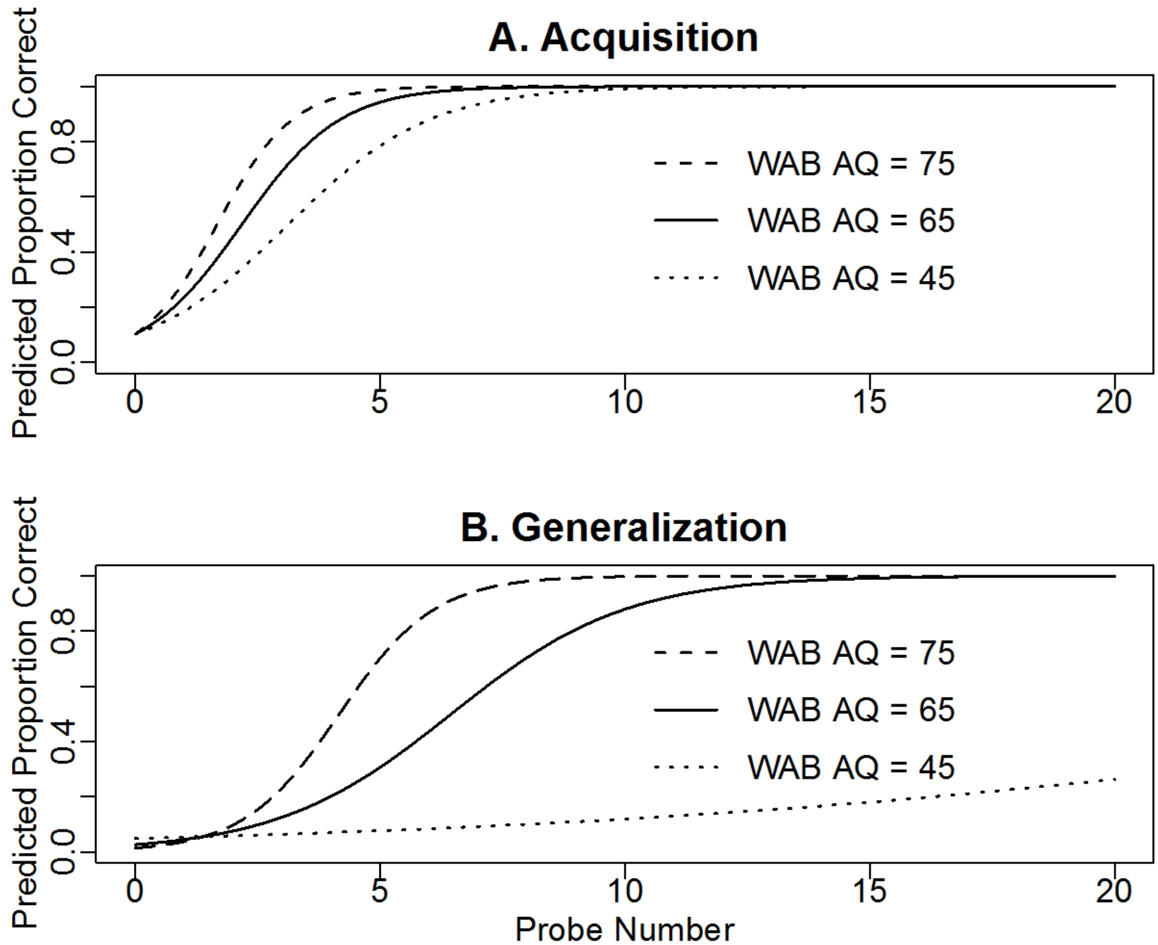

Figure 2. Plots of model-predicted treatment response curves for acquisition (Panel A) and generalization (Panel B) by aphasia severity.