Statistical Learning in Aphasia:
Preliminary Results from an Artificial Grammar Learning Task

Introduction

Statistical learning, i.e., the discovery of structure based on statistical properties of stimuli, is considered an implicit process that plays an important role in nonlinguistic and linguistic tasks, including speech segmentation and grammar learning (Aslin & Newport, 2012; Saffran, 2002; Saffran et al., 1996). Moreover, individual differences in statistical learning ability have been shown to be associated with natural language processing (Misyak & Christiansen, 2012; Misyak et al., 2010). Yet little is known about this type of learning in individuals with aphasia, who must relearn linguistic skills after brain damage. To date, studies of implicit learning processes in aphasia have provided mixed results, including evidence of limited or absent implicit learning for a visual artificial grammar (Christiansen et al., 2010; Zimmerer et al., 2014), as well as evidence of relatively intact implicit learning in Serial Reaction Time tasks (Goschke et al., 2001; Schuchard & Thompson, 2013). The purpose of the present study was to test statistical learning and overnight consolidation of an artificial phrase structure grammar under implicit conditions in individuals with agrammatic aphasia and healthy age-matched adults.

Methods

Eight individuals with chronic aphasia resulting from a single left hemisphere stroke (7 male; age 35-81, *M*=56) and 20 age- and education-matched healthy adults (9 male; age 32-75, *M*=57) participated in the study[1]. Aphasic participants exhibited symptoms consistent with agrammatism, as indicated by scores on the *Western Aphasia Battery-Revised* (WAB-R; Kertesz, 2007), *Northwestern Assessment of Verbs and Sentences* (NAVS; Thompson, 2011), and narrative sample analyses (see Table 1).

The artificial grammar in the study was adapted from the "Language P" used by Saffran (2002). In this language, monosyllabic pseudowords are assigned to one of five lexical categories and arranged according to the rules of a phrase structure grammar (see Figure 1). All sentence stimuli in the present experiment were 3-5 pseudowords in length. Fifty grammatical sentences were developed for the training sessions. Seven additional grammatical and fourteen ungrammatical sentences were developed for a grammaticality judgment test. Grammatical and ungrammatical test stimuli matched each other and the training stimuli in sentence length and the relative frequency of each pseudoword. All sentences were recorded by the same female speaker, and stimuli were presented using SuperLab software.

Healthy participants were randomly assigned to the training group (n=12) or to the control group (n=8) that did not receive training. Healthy participants in the training group and all aphasic participants were trained in the artificial grammar on two consecutive days. On the first day, participants listened to the set of 50 grammatical sentences in the artificial language, repeated 8 times for a total of 400 sentences (~30 minutes). To help keep participants alert during this training period, they also watched a muted nature video. After exposure to the language, participants completed the 28-item grammaticality judgment test, in which they were instructed to decide whether each item was a "good" or "bad" sentence in the language based on their exposure to "good" sentences during training. To assess overnight consolidation of learning, participants returned the next day and again completed the grammaticality judgment

[1] This is an ongoing study, with an anticipated n of 15 participants with aphasia.

test. Participants then received a second training session identical to the first and completed the grammaticality judgment test a third time. Untrained control participants completed the three tests on the same time schedule but did not receive the two training sessions.

Results

A 3 x 3 mixed ANOVA was performed to examine differences in grammatical test accuracy across groups and test times (see Figure 2). The ANOVA yielded a significant main effect of group ($F(2,24)=3.7$, $p<.05$). Post hoc tests using Tukey HSD correction for multiple comparisons revealed that the trained healthy adult group performed significantly better than the untrained control group ($p<.05$). The aphasic group did not significantly differ from the untrained control group ($p=.60$), but they also did not significantly differ from the trained healthy adult group ($p=.31$). Further analysis of the aphasic data used two-tailed one-sample t-tests to compare the group's accuracy to chance performance (50%) at each of the three test times. These tests revealed that aphasic participants performed significantly above chance on the first test ($t(7)=2.4$, $p<.05$), but not on the second ($t(6)=1.3$, $p=.25$)[2] or third ($t(7)=1.7$, $p=.13$) test times.

Inspection of individual data reveals that adults with aphasia performed similarly to trained age-matched healthy adults immediately following exposure to the artificial grammar (i.e., Test 1). In each group, approximately half of the participants scored above 60% accuracy. On the next day at Test 2, both healthy and aphasic individuals tended to score the same as or lower than their scores at Test 1, with healthy participants decreasing an average of 3.6 percentage points and aphasic participants decreasing an average of 4.1 percentage points. Accuracy on Test 3 showed the greatest difference between healthy and aphasic individuals, with only 4/8 aphasic participants scoring above 60%, compared to 10/12 healthy participants. Individual data for these two groups are displayed in Figure 3.

Across the three tests, both aphasic and healthy individuals' accuracy for untrained grammatical sentences was similar to their accuracy for sentences that were included in the training sessions. In the aphasic group, accuracy in identifying untrained grammatical sentences as "good" ($M=70.2$, $SD=22.2$) did not significantly differ from accuracy in identifying trained grammatical sentences as "good" ($M=64.9$, $SD=17.1$, $t(7)=-0.9$, $p=.39$). Similarly, for the trained healthy group, accuracy in identifying untrained grammatical sentences ($M=72.2$, $SD=16.3$) did not significantly differ from accuracy in identifying trained sentences ($M=72.6$, $SD=9.3$, $t(11)=0.1$, $p=.93$).

Discussion

Results from the present study provide preliminary evidence of statistical learning of a novel grammar under implicit conditions in individuals with aphasia. Immediately following a period of exposure to grammatical sentences, a group of adults with aphasia performed significantly above chance on a grammaticality judgment test, with individual variability similar to a trained healthy comparison group. Moreover, similar performance on trained and untrained grammatical sentences suggests that participants were able to extract patterns and generalize to novel stimuli, as opposed to only recognizing sentences presented during the training session.

However, the aphasic group did not perform significantly above chance on the two tests administered on the second day of the study. Little is known about overnight consolidation of learning in aphasia, and these results suggest that this important process may be impaired in some individuals. However, the greatest impairment for aphasic individuals was observed in the

[2] One aphasic participant discontinued Test 2 and thus does not have data for this time point.

final test. Results suggest that most healthy individuals were able to take advantage of the second training session and score at least 60% on the final test, whereas half the aphasic participants did not. This impairment in the aphasic group may be due to fatigue, adoption of an ineffective strategy on the second day of training, or other variables. The present study suggests that individuals with aphasia are able to take advantage of statistical learning processes, at least initially, but that overnight consolidation and accumulation of learning over multiple days are important factors that warrant further investigation.

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Tes t	P1	P2	P3	P4	P5	P6	P7	P8
Western Aphasia Battery-Revised								
Aphasia Quotient	71.7	77	82.5	78	88	77.2	76.6	83.8
Fluency	4	5	6	5	6	4	6	6
Information Content	9	9	10	10	10	9	8	9
Auditory Verbal Comprehension	8.45	8.4	7.55	7.9	9.8	8.3	8.8	9.3
Repetition	5.1	7.7	9	7.6	9.2	7.2	7.4	9
Naming and Word Finding	9.3	8.4	8.7	8.5	9	8.1	8.1	8.6
Northwestern Assessment of Verbs and Sentences								
Argument Structure Production								
1 argument verbs	100	100	100	100	100	100	100	100
2 argument verbs	100	93.3	93.3	100	100	86.7	93.3	100
3 argument verbs	58	100	91.7	83	91.7	50	41.6	91.7
Sentence Production Priming Test								
Canonical	33.3	53.3	80	46.7	100	46.7	80	100
Noncanonical	0	26.7	46.7	20	60	0	66.7	60
Sentence Comprehension Test								
Canonical	86.7	73.3	66.7	60	80	80	86.7	100
Noncanonical	80	93.3	73.3	73.3	46.7	26.7	46.7	80
Cinderella Narrative Analysis								
Mean length of utterance (words)	4.8	4.9	8.4	10.4	7.6	6.8	4.5	6.2
Percent grammatical sentences	18.8	12.1	93.3	47.5	64.3	0	30.0	53.7
Noun:verb ratio	1.5	1.3	1.3	0.9	1.6	1.4	2.0	1.3

Table 1. Language testing data for agrammatic aphasic participants (P1-P8).

a.

S → AP + BP + (CP)
AP → A + (D)
BP → CP + F
CP → C + (G)

b.

Category	Pseudowords	
A	biff	hep
C	cav	lum
D	vot	pell
F	dupp	loke
G	tiz	mib

Figure 1. Phrase structure rules (a, top) and lexical categories (b, bottom) of the artificial grammar used in the present study. Adapted from Saffran (2002).

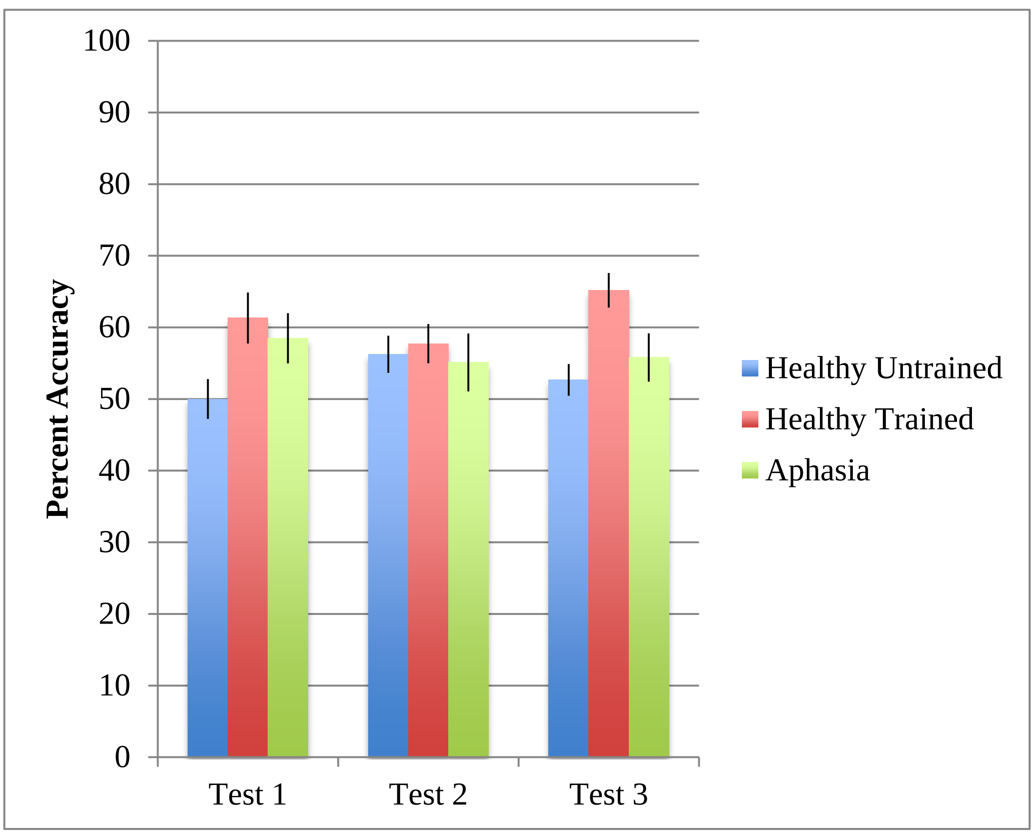

Figure 2. Mean percent accuracy on the three grammaticality judgment tests for the healthy untrained, healthy trained, and agrammatic aphasic groups. Error bars indicate standard error of the mean.

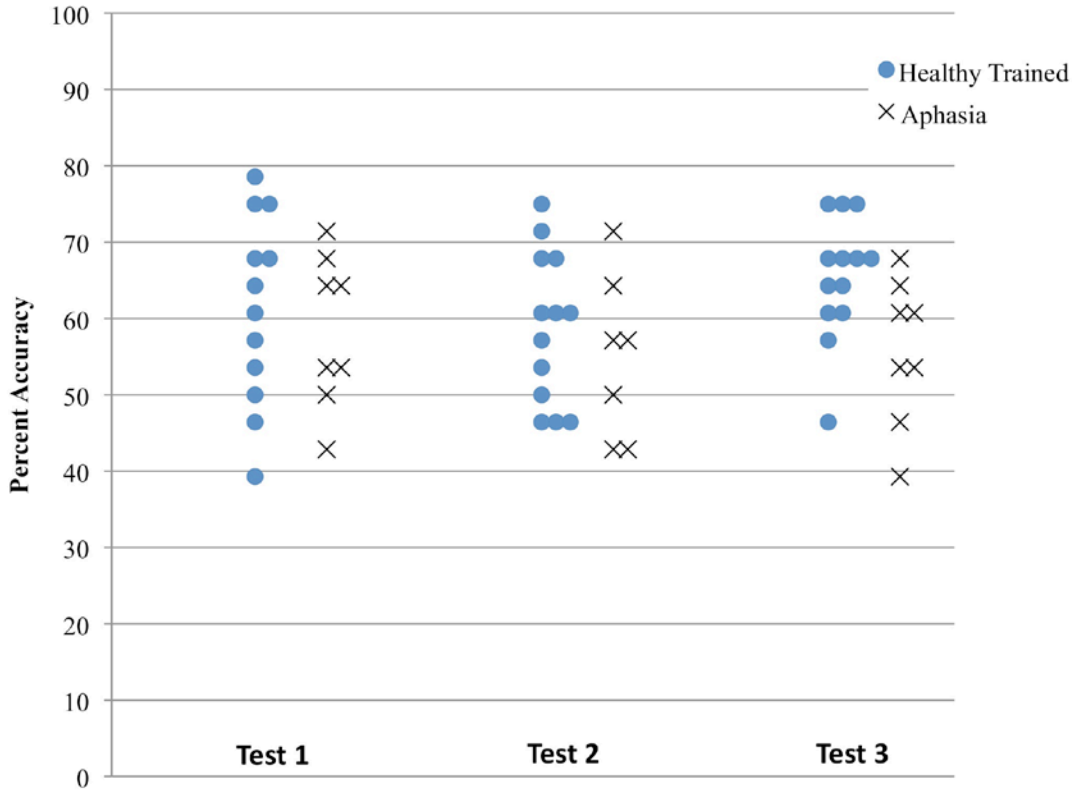

Figure 3. Individual scores on the three grammaticality judgment tests for trained healthy adult and agrammatic aphasic participants.