The persistence and obliteration of opaque interactions

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1 Introduction

Abstract linguistic representations have been a hallmark of linguistic theories from early structuralism (Baudouin de Courtenay, [1985] 1972) to modern generative theories (Chomsky, 1955; Chomsky, 1995). Within phonology, the incarnation of abstraction is the underlying representation (UR; Chomsky & Halle, 1968), the supposed mental representation of a word, which is used to generate its surface representation (SR). While recent approaches to generative phonology seek to minimize the degree to which a UR differs from an SR (e.g. Kiparsky, 1982; Prince & Smolensky, 1993), the notion of an underlying or prototypical representation (Samuel & Sumner, 2005) persists. Therefore, a crucial component of research in acquisition requires an understanding of how language learners are able to learn URs in tandem with acquiring the general sound patterns of their language.

Furthermore, the potential similarity between phonological abstraction and abstraction in other domains of cognition raises the question of whether phonological abstraction is domain-specific or can be explained through more domain-general cognitive function. This is a particularly important question in light of recent hypotheses about how memory systems support language acquisition and use (Ullman, 2004).

To investigate language-learners' capacity for acquiring abstract linguistic representations, we conducted an artificial grammar learning experiment (Braine, 1971; Esper, 1925; Reber, 1965; Wilson, 2003) using a language requiring both abstraction and acquiring phonological generalizations. Participants were trained on a language, and then tested on their ability to extrapolate the grammar to novel forms. To explore the role memory has in supporting the acquisition of generalizations and abstraction, these same participants took a battery of standardized cognitive and memory tests to assess whether performance on these general cognitive tests predicted language-learning success.

2 Background

Generative phonology posits an underlying representation for each word or morpheme in the lexicon. The UR is transformed into a surface representation through the serial application of rules (Chomsky & Halle, 1968) or parallel evaluation of constraints (Prince & Smolensky, 1993). For example, in English, the p in *pit* is articulated with aspiration, but in *spit* without. An analysis might posit /p/ as the underlying representation in both with a rule or constraint aspirating syllable initial plosives.

A number of studies have lent support to the idea that there is an abstract and/or prototypical mental representation of words. Lahiri and Marslen-Wilson (1991) found that the representation of vowel nasalization differs in English and Hindi. In English, where vowel nasalization is not contrastive, CV sequences with nasalized vowels prime both CVN and CVC words, suggesting the vowel representations in English are not specified for nasalization even though acoustically nasalized vowels are generally only present before nasals. Further supporting the existence of an underlying form, Sumner and Samuel (2005) explored how variation in the pronunciation of word-final *t* affected the degree of priming. They found that there was no difference in short-term priming between different phonologically legal variants of *t*-final words, while phonologically anomalous variants produced no priming effect. However, in the long-term, canonical basic *t* variants yielded the strongest priming effect despite their lower frequency.

With respect to speakers' ability to abstract underlying forms from varying heard tokens, Gaskell, Marslen-Wilson, and colleagues conducted a number of experiments showing that, when provided with the appropriate context, English listeners can undo processes of assimilation. For example, Gaskell and Marslen-Wilson (1998) found that listeners were faster and more accurate in monitoring for variants of coronal segments when the alteration was phonologically legal in the particular context (e.g. *greem beans*). Underlying coronals surfacing as different due to context also serve as better primes (Gaskell and Marslen-Wilson, 1996) when in licensed contexts. Gaskell and Marslen-Wilson (1996) also show that a sequence like *greem beans*, where the *n* is legally assimilated to a following labial, does not disrupt word recognition, suggestion an ability to abstract forms, or ascertain an underlying representation given a differing surface representation.

While these studies have focused on knowledge of underlying representations in English speakers, there have also been a series of artificial language learning experiments exploring participants' ability to learn new phonological generalizations. Finley and Badecker (2009) provide evidence for subsegmental phonological structure by training participants on an artificial language with vowel harmony. Vowel harmony is an extremely common process, whereby the vowels in a suffix change in to match or be more similar to a vowel in a stem. Participants were able to extend the pattern of harmony to new stem vowels suggesting some knowledge about organization of speech sounds beyond just segments. Similar experiments have looked for evidence for other phonological patterns aside from harmony (Peperkamp & Dupoux, 2006; Wilson, 2003).

No study has explored the acquisition of new abstract phonological representations and so no study has explored the interaction between the acquisition of generalizations and representation. While there have been myriad studies exploring the role of working memory in overall language learning and performance (Baddeley, 1992 for a review), only recently have attempts been made to establish a relationship between other memory subsystems and learning generalizations (Ullman, 2004); none have addressed abstraction.

In the present study, we explore these questions by training participants on a artificial grammar that requires both generalization and an extreme example of abstraction referred to as phonological opacity (Kiparsky, 1973).

In opacity, two generalizations interact yielding one untrue in a certain subset of words. Consider, for example, the phonological patterns in Shimakonde (Liphola, 2001; Ettlinger, 2008), an African language spoken in Mozambique. Shimakonde exhibits mid vowel height harmony where high vowels [i] change to mid [e]. This may either be a result of co-articulatory pressure, or a way or increasing the perceptual salience of the this mid vowel – by having the mid vowel show up in multiple syllables it is less likely to be misperceived given the general difficulty of correctly hearing [e] relative to [i] and [a].

(1) Shimakonde harmony

	Stem		Applicative	
a.	kú-píít-a	'to pass'	kú-pít-**íí**l-a	'to pass for X'
b.	kú-páát-a	'to cut'	kú-pát-**íí**l-a	'to cut for X'
c.	kú-péét-a	'to separate'	kú-pét-**éé**l-a	'to separate for X'

There is also a process of mid vowel reduction, where mid vowels, [e], are articulated as low [a] when preceded by an [a]. Reduction is due to the difficulty of hearing mid vowels and its tendency to be misperceived as [a].

(2) Shimakonde reduction

	Stem		Future	
a.	kú-píít-a	'to pass'	vanda-pít-aan-a	'will pass'
b.	kú-páát-a	'to cut'	vanda-pát-aan-a	'will cut'
c.	kú-péét-a	'to separate'	vanda-pát-**aa**n-a	'will separate'

Combined together, these yield a generalization that make a strong case for the need for abstract URs:

(3) Shimakonde harmony

	Stem		Future Applicative	
a.	kú-píít-a	'to pass'	vanda-pít-ííl-a	'will pass for X'
b.	kú-páát-a	'to cut'	vanda-pát-ííl-a	'will cut for X'
c.	kú-péét-a	'to separate'	vanda-pat-**éé**l-a	'will separate for X'

In the opaque form (c), the applicative suffix is the target of vowel harmony due to the mid vowel in the root, and the mid vowel in the root is reduced to *a* in the surface because of reduction. There is no way to account for why the applicative suffix is *-el-* without reference to the underlying mid vowel in the stem.

From the perspective of the language learner, two sets of things must be learned. First, the generalizations in (1) and (2) must be acquired. Second, consider what the learner must do on hearing the form *vanda-pat-éél-a*. To correctly derive the form for ‘separate’, she cannot simply remove the prefixes and suffixes. This would lead to the belief that the stem is *pat*. Instead, she must undo the generalizations or establish a complex analogical relationship between forms to determine that the base form for ‘separate’ is actually pet. Similarly, if given the form /pet/ to inflect, the language learner must ascertain that the correct form of the suffix is based on the underlying or stem form of the word ‘separate’, and not its surface realization as [pat] (due to reduction), otherwise the learner would say [vandapatiila] for ‘will separate for’.

If the abstraction is not correctly learned, this yields what is referred to as a transparent interaction. In the transparent form, the future applicative for [pet] is simplified to [vanda-pat-iil-a] and a form like [vanda-pat-éél-a] yields [pat] as the stem. So, there are four logical possibilities of what the participants may acquire: both generalizations and abstraction (LEARNERS), just generalizations and no abstraction (a transparent grammar, LEVELERS), just abstraction (ABSTRACTERS), or neither (NON-LEARNERS).

3 Artificial Language Learning

3.1 Method

There were two stages of the artificial language learning task. First, participants were trained on words of the language then they were tested on untrained items to assess their acquired knowledge of the grammar.

3.1.1 Participants

Thirty-six (10 male) native English speakers participated in this experiment. Their mean age was 20.7 (SD=1.9), and all were students at Northwestern University and received monetary compensation. Participants were assigned to one of three experimental conditions detailed below.

3.1.2 Stimulus

The artificial language is similar to that in (1-3) but instead of verbs, uses nouns. The language has 30 noun stems and two affixes, a prefix, *ka-*, marking the diminutive, and a suffix, *-il*, marking the plural. The nouns represent 30 different animals and objects, which can combine freely with the affixes to produce up to 120 different words: the bare noun for a single large object, a noun with the plural suffix for multiple large objects, a noun with the diminutive prefix for a single small object, and the noun with both affixes for many, small objects.

The phonological inventory of the language is a subset of American English and consists of all the consonants and a 3-vowel system, /i, e, a/, articulated using an American English pronunciation so that new phoneme categories need not be learned. All nouns were CVC and existing English words were avoided.

As with Shimakonde, the language has harmony and reduction triggered by and targeting mid vowel (4b, 5b) yielding the same sort of opacity (6):

(4) Vowel harmony:

	Stem	Plural
a.	fin	fin-il
b.	mez	mez-**e**l
c.	vab	vab-il

(5) Vowel reduction:

	Stem	Diminutive
a.	fin	ka-fin
b.	mez	ka-m**a**z
c.	vab	ka-vab

(6) Opaque interaction:

	Stem	Dim/Pl.
a.	mez	ka-maz-**e**l

A native American English speaker was recorded saying each word at a normal speech rate with English prosody and phonology so as to sound fluent. Stress was on the noun stem and amplitude was normalized across stimuli.

3.1.2.1 Counter-balancing by vowel

In (4) & (5) above, vowel harmony and lowering respectively are triggered by and affect the mid vowel, e. This opens up the possibility that a bias for recalling and answering with one particular vowel could impact the results. Therefore, two other conditions were included with each of the other two vowels triggering and subject to vowel alternations.

3.1.3 Procedure

Participants were told that they would be exposed to a language without explicit instruction on the rules of the language and that their task was to learn the language from the example words they heard. The words were presented over headphones and the pictures presented on a computer screen. During testing, the participants recorded their responses on a button box.

3.1.3.1 Training

Training consisted of exposure to word-picture pairings along with testing with feedback. During exposure, each participant was exposed to 3 repetitions of 12 of the nouns in all 4 forms for a total of 144 words in pseudo-random order. Each picture was on the screen for 3 seconds with an ISI of 1 second. Each audio recording was approximately 1 second long and would start 500 milliseconds after the picture appeared.

For example, a participant saw the picture in Figure 1 and heard *kagadel*, the word for horse (*ged*) with the plural and diminutive affixes.

At the conclusion of each training session, participants were given a self-timed break, then given a test to evaluate their knowledge of trained nouns.

During the testing of trained items, participants saw a picture of a noun and heard two words in a two-alternative forced-choice task where the incorrect word reflected the transparent grammar discussed above (e.g. kagadel vs. kagadil). They were instructed that the left button corresponded to the first-heard word and the right button corresponded to the second-heard word. Every training item was tested once, in random order, for a total of 48 test items. The first word was heard 500 milliseconds after the picture appeared, the second word was heard 1500 milliseconds after the first (with an ISI of around 500 milliseconds, depending on word length) and participants had 3 seconds after the beginning on the second word to respond. Each response was followed by a feedback screen lasting 2 seconds indicating whether the response was correct, their reaction time, and a running total of percent correct. A blank screen separated each trial for 1 second.

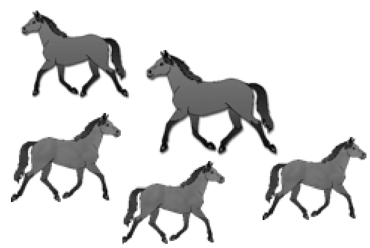

Figure 1: Example visual stimulus for experiment one for many small horses *kagadel*

3.1.3.2 Test of untrained items

At the end of the training session, participants were tested on their ability to apply the grammar they learned to new forms in a version of a wug-test (Berko, 1958). Participants saw a new picture with a new noun (from the group of 18 withheld nouns) for 1500 millisecond and heard the corresponding word. This was followed by a blank screen for 1 second, then another picture with the same noun but a different form. For example, the first picture would be a lion and the second would be many small lions. As in the previous test, they were required to select from 2 heard alternatives, but without feedback. All 4 inflections of the 18 withheld nouns were tested in random order for a total of 72 items. Each trial required two pictures, different pairings of the first and second picture tested different aspects of what was acquired.

To test the acquisition of the generalizations (harmony, reduction) the singular was used to prompt the plural (*pe□□pe□el*) and the plural was used to prompt the diminutive (*pe□el□kapa□*). To test acquisition of abstraction, the diminutive plural was used to prompt the singular (*kapa□el□pe□*). Knowing that [pe□] is the singular form of [kapa□el] cannot be ascertained through simple exemplar models of acquisition with the [-pa□-] portion of the complex word serving as an exemplar for the lexical entry. Rather, participants must either undo rules to obtain the underlying abstract form or conduct a complex four-part analogy. A process of abstraction involving rules would notice the presence of the [ka-] prefix, which suggests that the second [a] in [kapa□el] could be originally [e]. The presence of the [-el] suffix in [kapa□el] confirms the original /e/. An alternate approach would be to establish a four-part analogy with old and new forms:

ged:kagadel::___:kapa□el. Participants would have to recognize the importance of the vowel pattern and know to ignore similar stimulus pairs such as *vab:kavabil*.

3.2 Results & Discussion

Because the test was a 2AFC, being significantly above chance (50%) reflects success. Participants performed the same across the three languages: percent correct on the new test items for the opaque vowel was 55% (SD=.22) for the i-opaque language, 53% (SD=.28) for the e-opaque language and 55% (SD=.26) for the a-opaque language. These differences are not significant ($F(2, 35)=.097$, $p=.91$), and so the three languages are grouped together for the remaining analyses. Performance on trained test items was high (84%), and above chance ($t(35)=15.2$, $p<.001$) collectively, and for each individual participant, so none were excluded from the analysis. On new items that require acquiring the affixes but none of the generalizations or abstraction (*i* and *a* stems), performance was also above chance (66.5%; $t(35)=4.80$, $p<.001$).

3.2.1 Abstraction

Performance was 52% correct on items requiring abstraction, which is not significantly different than chance ($t(35)= 0.33$, $p=.75$). However, this cumulative score combined participants that learned the language, those that acquired the simpler, transparent language discussed above, along with those that did not. Because the foil response reflected the transparent non-abstraction grammar, we can divide participants into those that learned the language (above chance; LEARNERS), those that did not (not above chance; NON-LEARNERS) and those that simplified the language (below chance; LEVELERS). There were 14 learners, 10 non-learners, and 12 levelers by this criterion.

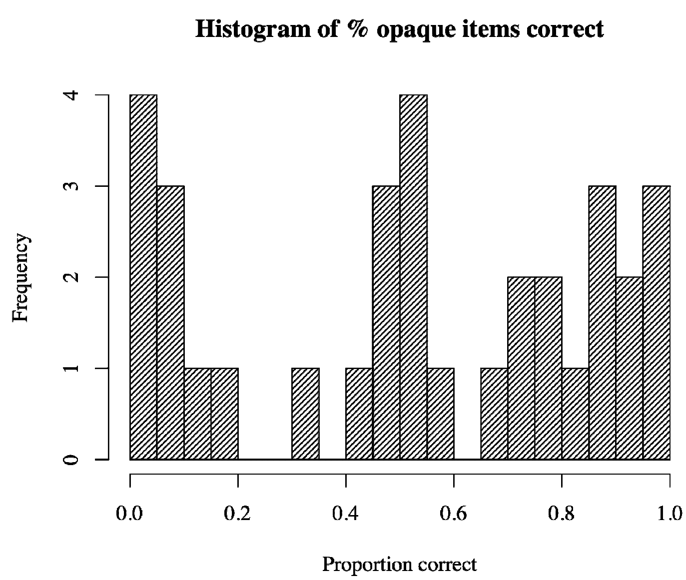

Figure 3: Histogram of percent of opaque items answered correctly

Further evidence comes from the overall distribution, which is not normal (Shapiro-Wilk normality test, W(35)=.91, p=.001 where p<.1 is generally considered adequate, Royston, 1995) and the histogram in Figure 3.

The transparent version of the language acquired by levelers involved learning the generalizations but not the abstraction necessary to go from [ka-gad-el] to [ged]. Instead, those that reconstructed a transparent grammar consistently selected [gad] in contrast with the non-learners that had no consistent response for the novel words.

Learners, non-learners, and levelers did not differ with respect to their performance on items requiring neither abstraction nor generalization (71%, 65%, 63% respectively, F[2, 30]=.56, p=.577). This suggests that performance on abstract forms does not reflect a general ability, attention, or some basic language-learning ability, rather it focuses on a narrow language-learning skill.

3.2.2 Generalization

Overall, participants were correct on 65% of items requiring generalization, significantly above chance ($t(35)=5.6$, $p<.001$). By group, learners and leveler groups both performed above chance on items generalization items (74% and 70% respectively, $t(13)=4.3$, $p<.001$; $t(11)=2.8$, $p=.008$) and not significantly different from each other (unpaired t-test: $t(22.8)=.94$, $p=.35$). Non-learners were not above chance on generalization items (53%, $t(9)=.38$, $p=.71$).

3.2.3 Relation between Generalization and Abstraction

A second-order regression shows that a significant proportion of variance in performance on the generalizations is accounted for by performance on abstract items (F[2, 33]=5.9, $p=.0018$; $R^2=.28$; figure 4).

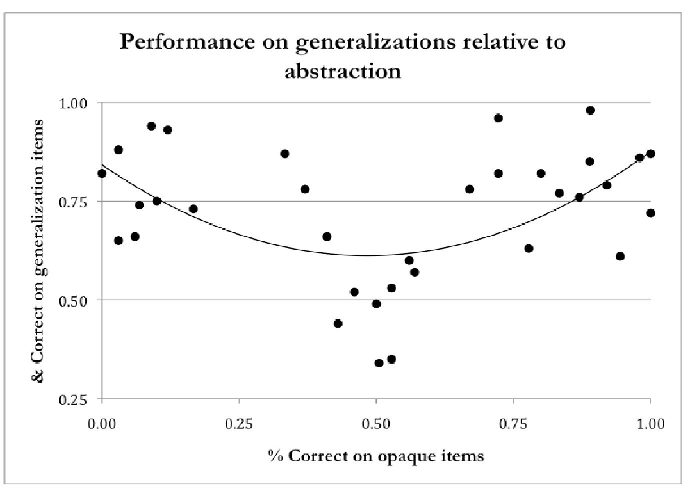

Figure 4: Performance on acquiring generalizations relative to the opaque interaction

This confirms that those that performed both significantly above or below chance (learners and levelers) on the abstract forms acquired a grammar reflecting the correct phonological generalizations. So, performance below chance on the abstract items is not considered poorer performance than at-chance.

Furthermore, of the four logical possible outcomes discussed above, only three groups emerge as only one individual that is different than chance on the abstract items is not above chance on the generalization items (ABSTRACTER). That is, only one person acquired the abstraction without acquiring the generalizations suggesting that acquiring the generalizations is a precursor to being able to abstract forms. This lends support to the procedural account of abstraction rather than the analogical one where knowledge of the generalizations is not a precursor to being able to conduct the analogy. Through analogy, more participants should be able to acquire the abstract forms without learning the generalization (i.e. learners with low generalization scores). The procedural account correctly predicts that all learners must necessarily acquire the generalizations.

3.3 Summary

Taken together, these results provide evidence that there are three types of learners. Some individuals acquire the complete grammar including the ability to correctly abstract forms in the artificial language. Others only acquire the generalizations and not the abstract portion of the grammar, while a third group acquires neither. Our next set of questions concerned whether these individual differences in the ability to form abstractions were related to other cognitive capabilities, particularly memory.

4 Associating Language Learning and Memory

Since the introduction of the notion of a language acquisition device (Chomsky, 1965), the mental organ responsible for the acquisition of language, researchers have sought to divide the language faculty in a broad faculty of language (FLB) and a narrow faculty of language (FLN) (Hauser, Chomsky & Fitch, 2002). The FLN represents the portion of the language faculty specific to language and independent of other mental capacities, while the FLB includes general cognitive capabilities that support the acquisition and use of language. While the question of what the FLN remains controversial, myriad studies have demonstrated how general cognitive capabilities (FLB) support language.

Baddeley and colleagues (see Baddeley, 1992 for a review) have shown that working memory plays a crucial role in all levels of language learning and processing. While this represents a significant contribution to the way general cognitive capabilities support language, it is unsurprising given working memory's role in nearly every cognitive endeavor.

A more specific hypothesis, the Declarative/Procedural hypothesis (D/P; Ullman, 2004) associates certain linguistic functions with different types of memory. Words (lexicon) are associated with declarative memory, while grammar, operating over lexical items, combining and modifying them, is associated with procedural memory. Evidence for the D/P has focused almost exclusively on English, and the English past tense in particular, and it has focused on the use, and not the acquisition, of grammar. We address this shortcoming here by looking at the cognitive underpinnings of the acquisition of a complex morphophonological process.

4.1 Method

As the above results showed, in a language that has both abstraction and generalization, we find that learners pattern into one of three groups, those that learn everything, those that learn just generalization without abstraction, and those that learn neither. To explore the relationship between memory and these different levels of learning success, the same participants took a battery of standardized general cognitive tests. All but two participants returned for these tests.

The tests included two subtests of the Woodcock–Johnson III Tests of Cognitive Ability (Woodcock, McGrew & Werder, 2001): Visual-Auditory Learning, and Auditory Working Memory, as well as the Tower of London test (TOL; Shallice, 1982). The Visual-Auditory Learning test is an assessment of declarative, and in particular short-term, memory and the Auditory Working Memory test is an assessment of working memory. The TOL test is a general measure of executive function and improvement in performance over time is reflective of procedural learning (Phillips et al., 2000). The TOL task serves to minimize the role of motor skills in performance as compared to other tests of procedural learning such as a the serial reaction time task (Spreen and Strauss, 1998), thereby isolating procedural learning. For Woodcock-Johnson scores, participants were scored relative to the tests normalized data; for the TOL task, participants were normalized relative to the study group.

The assessment of procedural and declarative memory serves to test the D/P hypothesis. If a significant amount of the variance in the learning of this complex interaction is accounted for by performance on these cognitive tests, it lends support to the idea that particular types of memory support the acquisition of this aspect of language. Also, an assessment of working memory serves to control for general intelligence to differentiate these findings from prior studies showing a relationship between working memory and language ability. This experiment aims to show a relationship between a specific type of linguistic phenomenon – abstraction – and a particular type of memory.

4.2 Results

The previous experiment showed that people generally fell into three categories when it came to learning an artificial language with both abstraction and generalization: Those that learned both, those that learned just the generalizations, and those that learned neither. Therefore, we used the three groups discussed above to compare performance on the standardized memory measures.

4.2.1 Overall findings

The overall results of the battery of cognitive tests are shown in Figure 5.

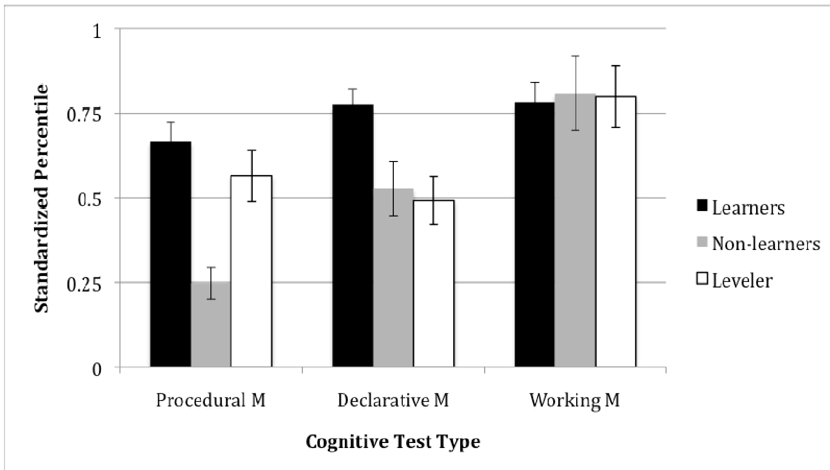

Figure 5: Performance on cognitive tests by learner type. TOL= change in TOL time, AS=WJIII analysis-synthesis, VL=WJIII visual learning, WM=WJIII working memory

An analysis of variance shows that procedural memory performance is significantly different by learner-type (F[2,30]=15.4, $p<.001$), as is declarative memory (F[2, 30]=3.6, $p=.031$). Working memory is not significantly different between learner groups (F[2,30]=.057, $p=.94$), thereby acting as a successful control. So, it is not working memory (Baddeley, 1992) or general intelligence driving the variance in learning this particular aspect of the language and corroborates the results showing similar performance on simple forms and trained items across groups.

4.2.2 Procedural Memory

For procedural memory, post-hoc unpaired t-tests show that learners and levelers are significantly better than non-learners ($t(19)=7.0$, $p<.001$; $t(13)=3.4$, $p=.0042$ respectively), and learners and levelers are not different from each other ($t(17)=1.3$, $p=.21$). Furthermore, a second-order polynomial regression between complex language learning and performance on the procedural is significant (adjusted $r^2=.305$, $p(30)=.0017$; Figure 6). The homology between this graph and Figure 3 suggests that procedural learning correlates with the ability to generalize. This is borne out by the significant correlation between procedural memory and performance on the generalization items across all groups (Pearson's $r(31)=.55$, $p=.001$).

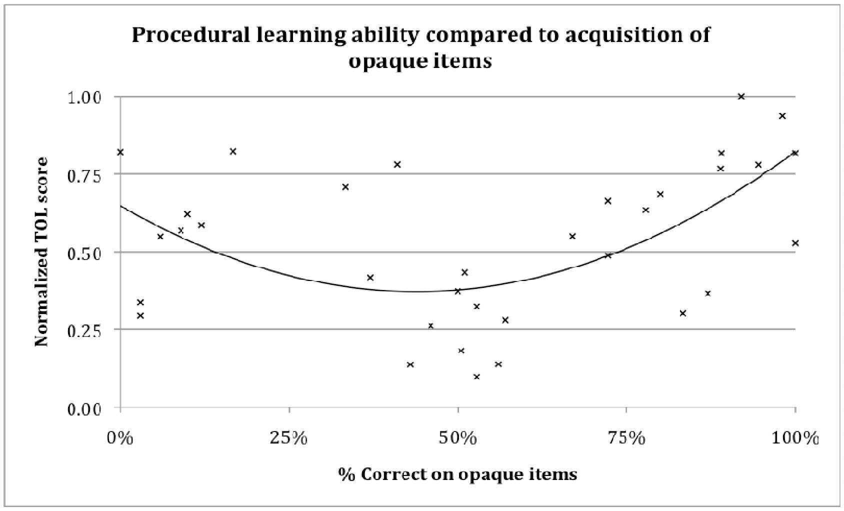

Figure 6: Performance on test of procedural memory versus performance on opaque items.

4.2.3 Declarative Memory

For declarative memory, learners are better than both levelers and non-learners ($t(15)=2.6$, $p=.022$; $t(15)=2.23$, $p=.034$). There is also a significant correlation between declarative memory and performance on abstract items ($r(31)=.39$, $p=.025$): the better the participants' declarative memory, the better they were able to perform the abstration necessary to correctly answer the opaque forms.

4.2.4 Alternate grouping

We also compared results on the different tasks using a tercile split with three groups of 12 to avoid the possibility that our criteria dividing participants into groups was arbitrary. An ANOVA shows that procedural memory performance is significant ($F[2,30]=9.7$, $p<.001$) as is declarative memory ($F[2, 30]=2.09$, $p=.05$)

4.3 Discussion

Juxtaposing how the different groups did on the memory tests to what they acquired in the artificial language suggests that procedural memory is associated with the acquisition of the generalizations, while declarative memory is associated with the process of abstraction. Learners, who acquired both abstraction and the generalizations, were good at both tasks; levelers, who acquired the generalizations, but not abstraction, were good at the procedural learning task, but not the declarative memory task; and non-learners were good at neither.

A scatter plot of procedural and declarative memory measures provides a clearer profile of the learner types. Those that were good at both are primarily learners (top right quadrant), those that were good at procedural, but not declarative memory, are primarily levelers (bottom right), while those that with poor procedural memory are non-learners, regardless of declarative memory.

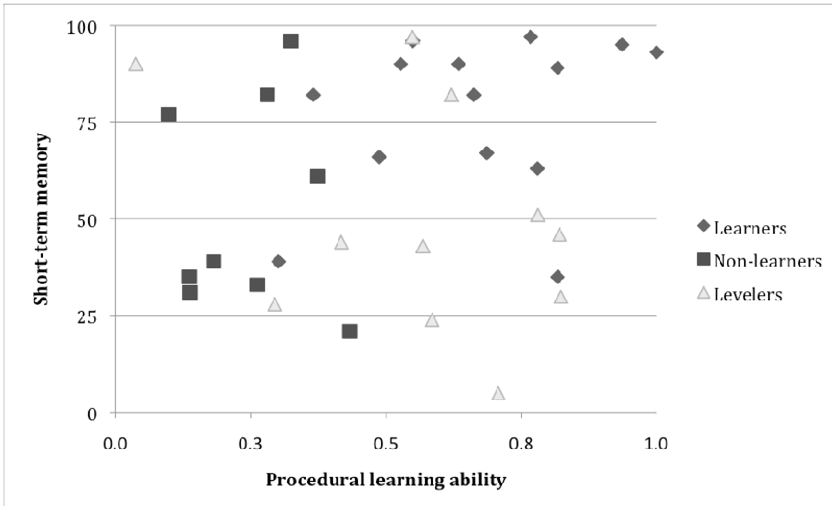

Figure 7: Scatter plot showing particpants performances on both procedural learning and short-term memory tasks, grouped by language-learning ability.

Overall, these data present a picture of language acquisition where procedural memory supports the acquisition of phonological generalizations, conotrolling for other types of memory, attention and broad language learning capabilities (controlled performance on working memory task and simple forms). On the other hand, abstraction is dependent on declarative memory. If we take declarative memory to be the memory subsystem associated with word learning (Ullman, 2004), this suggests that abstraction involves the recruitment of other word forms, i.e. an analogical process. Ullman (2001) has suggested that declarative memory is crucial for the acquisition of grammar in second language learning for memorization of larger units that are eventually broken down. This cannot be the case here, however, since participants are being tested on novel words. In light of the present findings, the findings of Ullman (2001) with respect to the role of declarative memory can be understood to reflect the importance of stored word forms and declarative memory in the acquisition of a grammar itself, blurring the disassociation of words and rules, but still presenting a system where acquiriting certain elements of grammar are dependent on general cognitive capabilities.

5 Discussion

These results suggest that the artificial grammar learning paradigm can be effectivey used to test people's ability to learn abstract representations of speech whereas only the acquisition of generalization has been demonstrated prior. When these two aspects of acquisition are juxtaposed, the data suggest that the acquisition of one – abstraction – is dependent on the acquisition of the other – generalization – and not the other way around. That is, generalization is a *sine qua non* for abstraction.

These results also contribute to the broader aim of acounting for various aspects of language and language acquisition by means of domain-general cogitive function, further demistifying the uniquieness of language. In particular, they suggest that the acquisition of phonological generalizations be associated with procedural memory, which, at a broad level, supports the D/P hypothesis. This represents the first attempt to show the relationship between procedural and declarative memory and language acquisition, as opposed to the significant evidence already found for language use.

Crucially, the data investigating the relationship between general cognitive capabilities and language learning also focus on an area ignored by the D/P hypothesis. In the D/P hypothesis, abstraction is essentially ignored. Here, we find that it crucially depends on declarative and not procedural memory. Associations amongst elements are an integral componenet of declarative memory (Cohen, 2003) suggesting that a theory of abstraction and opacity based on analogy and association is more promising than one based on serial derivations, which is more likely to be associated with procedural memory. This fills in a crucial missing component to the D/P hypothesis, which focuses exclusively on affixation in establishing a double dissassociation between rules and words. These results here suggests a more complex picture with complex grammatical rules derived from the words in the lexicon as suggested by theories like OT.

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