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Declarative and procedural memory abilities as individual differences in incidental language learning

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ABSTRACT

This study investigated whether individual differences in declarative and procedural memory abilities predicted the learning and retention of second language (L2) syntactic structures under incidental conditions. Participants were exposed to novel syntactic structures in a semi-artificial language paradigm under incidental learning conditions. After exposure, they were given a surprise recognition task in which they were asked to discriminate old and new sentences, which only could be done on the basis of their syntactic structures. Participants were then given an identical surprise test after a period of no exposure. Declarative memory abilities predicted performance on the immediate, but not delayed, recognition task, whereas procedural memory abilities predicted performance on the delayed, but not immediate, recognition task. The results demonstrate that the previously-reported relationships between declarative and procedural memory abilities and L2 development under intentional learning conditions can also be found under incidental learning conditions.

1. Introduction

Recent research has posited roles for two long-term memory systems, declarative and procedural memory, in second language (L2) learning (Morgan-Short & Ullman, 2012; Ullman, 2005, 2015, in press). These memory systems differ along a number of dimensions, including their relationships with awareness, the computations they perform, and the neural substrates subserving them (Eichenbaum, 2002; Eichenbaum & Cohen, 2001). For example, declarative memory supports the learning of general facts and knowledge (i.e., semantic memory) and autobiographical events from one's life (i.e., episodic memory; Tulving, 1993). Declarative memory is also argued to support both explicit (i.e., with awareness) and implicit (i.e., without awareness) forms of knowledge (Ullman, 2005). Procedural memory, on the other hand, supports motor and cognitive skill learning (Knowlton & Moody, 2008), and appears to underlie the acquisition and execution of sequential skills, such as learning to play a musical instrument. Learning and forgetting in this system are thought to be slower than in declarative memory. Procedural memory consists of implicit knowledge inasmuch as the knowledge contained there is difficult to verbalize and access via introspection.

Several researchers have linked these two long-term memory systems with language functions in children and adults. Both Paradis (2004, 2009) and Ullman (2001, 2004, 2005, 2015, in press) have posited that declarative memory and procedural memory are involved in the acquisition of lexicon and grammar, respectively. For example, Ullman's declarative/procedural (DP) model proposes that in one's first language (L1) declarative memory underlies the acquisition and representation of information stored in the lexicon, including words and grammatically complex forms memorized as whole chunks (due to their frequency). Procedural memory is posited to underlie aspects of grammar thought to rely on combinatorial processing, such as morphosyntax and syntax. The situation in L2 development is hypothesized to be different to some degree. As in the L1, L2 lexical development is argued to rely on declarative memory; however, in contrast to L1 grammar, early L2 grammatical development is argued to rely on declarative memory and this reliance may persist for some time (possibly forever, depending on a factors such as proficiency). It is only in certain circumstances that L2 grammar learning takes place in the procedural system.

Increasing evidence from electrophysiology (e.g., Morgan-Short, Finger, Grey, & Ullman, 2012; Morgan-Short, Steinhauer, Sanz, & Ullman, 2012) and neuroimaging (Morgan-Short et al., 2015; Tagarelli, 2014) supports these predictions. Recent work also indicates that individual differences in declarative and procedural memory abilities correlate with L2 learning (Carpenter, 2008; Morgan-Short et al., 2015; Morgan-Short, Faretta-Stutenberg, Brill-Schuetz, Carpenter, & Wong, 2014). For example, Morgan-Short et al. (2014) investigated whether individual differences in declarative and procedural memory abilities were related to learning of the artificial language Brocanto2 under "implicit" conditions. While the authors label these conditions "implicit,"

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they are more similar to intentional learning conditions[1] because participants "were told that they would be learning an artificial language" (Morgan-Short et al., 2014, p. 63). The authors found that their behavioral measures of declarative memory (the paired-associates task from the MLAT-V and a Continuous Verbal Memory Task) predicted grammar learning in Brocanto2 early in training, but not in later stages of training, while measures of procedural memory (Tower of London and Weather Prediction Tasks) predicted their grammar abilities in later phases but not earlier phases of learning, consistent with the predictions of the DP model.

Importantly, these studies supporting the DP model in L2 learning have relied on more intentional learning conditions.[2] However, it has been argued that individual differences are less likely to play roles under more implicit learning conditions (Reber, Walkenfeld, & Hernstadt, 1991; although, see Kaufman et al., 2010; Robinson, 1997, for alternate views), which arguably include more incidental learning conditions. This view has been largely supported in L2 research. For example, several studies have shown that individual differences in working memory predict L2 development in more intentional learning conditions (e.g., Brooks, Kempe, & Sionov, 2006; Kempe & Brooks, 2008; Martin & Ellis, 2012; Tagarelli, Borges Mota, & Rebuschat, 2011, 2015), whereas the relationship between working memory and L2 learning is less clear under incidental conditions, in large part due to mixed results in previous studies. For example, Robinson (2005) found that working memory capacity (assessed by a reading span task) correlated with learning of Samoan syntax under incidental conditions as assessed by an aural, but not visual, grammaticality judgment task (GJT). However, it is unclear whether working memory correlated with learning under incidental conditions because of common underlying mechanisms or because of task demands. Using a semi-artificial language paradigm, Tagarelli et al. (2011, 2015) found no correlations between working memory scores on an operation-word span task or a letter-number ordering task and the acquisition of word order information under incidental learning conditions. Similarly, Grey, Williams, and Rebuschat (2015) found that phonological working memory did not correlate with incidental learning of L2 word order or case marking in a semi-artificial language.

Do learning conditions similarly modulate the relationships between L2 learning and declarative/procedural memory? It is possible that individual differences in declarative and procedural memory correlate with L2 learning but only under more intentional conditions, perhaps in the same way that working memory has been shown to be. On the other hand, if declarative and procedural memory show similar correlations with L2 learning under both intentional and incidental conditions, then it is possible that these memory systems are more associated with language learning in general, rather than being dependent upon specific learning conditions.

2. The present study

The present study set out to investigate the relationships between individual differences in declarative and procedural memory abilities and L2 grammar learning under incidental conditions. Declarative memory abilities were assessed via the LLAMA-B (Meara, 2005), which is a paired-associates task modeled on the MLAT-V paired-associates task used by Carpenter (2008) and Morgan-Short et al. (2014). Procedural memory abilities were assessed by means of a modified serial reaction time (SRT) task (Nissen & Bullemer, 1987). Two research questions were addressed:

1. Is there a relationship between declarative and/or procedural memory abilities and L2 syntactic development under incidental learning conditions?
2. Does a period of no exposure between the exposure phase and testing affect any relationships between declarative and/or procedural memory abilities and L2 syntactic development?

In response to the first research question, it was predicted that declarative, but not procedural memory, abilities would positively correlate with L2 syntax learning abilities when participants were tested immediately after an incidental exposure phase. This prediction follows from the various proposals that declarative memory supports rapid learning in the early phases of L2 grammatical development (e.g., Paradis, 2009; Ullman, 2005). The second research question was motivated by the findings of Morgan-Short, Finger, et al. (2012), who found that L2 training followed by three to six months of no exposure led to more native-like electrophysiological signatures of grammatical processing. One interpretation (but not the only one[3]), is that these native-like signatures show up after no exposure due the slower rates learning and forgetting in procedural, relative to declarative, memory. Following this possibility, it was predicted that procedural, but not declarative, memory abilities would correlate with L2 syntax learning abilities when participants were tested after a period of no exposure.

3. Method

3.1. Participants

Thirty-one monolingual native-speakers of English were given extra credit in their courses to participate in the study (26 females, 25 undergraduates, 6 graduate students, $M_{age} = 21.4$, range: 18–29). All 31 participants completed session one. When participants were asked to return after a one-week minimum interval, 20 participants returned. Due to technical failures, data for all tasks (immediate and delayed recognition tests, SRT task, and LLAMA-B) were only obtained for a total of 18 participants. No participants had prior knowledge of Persian, which was the basis for the syntactic structures used in this study. No participant had taken more than one year of another language in college. All participants reported having normal or corrected-to-normal vision and hearing.

3.2. Materials

3.2.1. Measure of declarative memory

Participants' declarative learning abilities were assessed via the LLAMA-B (Meara, 2005). The LLAMA-B was designed, like the paired-associates task in the MLAT-V, to assess verbal declarative learning and vocabulary learning abilities. In the LLAMA-B participants are asked to memorize words (e.g., "cauac," "akbal," "muluc") that are arbitrarily paired with images of imaginary creatures. Participants are told to study these word-object pairings for two-minutes, after which they will be given a test. In the test phase, participants are cued with a given word and must select the corresponding object. Participants are given accuracy feedback during the test phase, but not during the study phase.

3.2.2. Measure of procedural memory

Procedural learning abilities were assessed with a modified version of the SRT task (Nissen & Bullemer, 1987) adapted from Lum and Kidd (2012). In this task, participants are given a repeating 10-item sequence. The sequence consists of the presentation of a circle inside four squares placed in diamond-shaped pattern on the computer screen. Each location on the computer screen corresponded to a button on a Logitech

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[1] Throughout this paper, I refer to any learning conditions in which participants are told (a) to learn and/or (b) that they will be tested as intentional learning conditions (Hulstijn, 2003).

[2] Other research has shown similar correlations between L2 development and common measures of declarative and procedural memory (e.g., Granena, 2013; Linck et al., 2013); however, these studies were not focused on learning conditions and, hence, did not control whether learning was incidental or intentional.

[3] One reviewer rightly points out that other possibilities include procedural memory-supported responses based on processing rather than content retrieval.

USB gamepad connected to the computer. The orientation of the squares on the computer screen and the corresponding buttons on the gamepad was identical and was always the same across trials for every participant. During testing, participants sat approximately 20 in. (50 cm) away from the computer screen. Participants were told that the task was simply a motor speed task. Participants were not informed that they would encounter both random and patterned sequences. They were not informed that their goal was to learn anything.

Participants were initially exposed to one block[4] of pseudorandom sequences. This was followed by four blocks of a patterned sequence (e.g., 1–3–4–2–3–1–4–2–1–4, with the numbers corresponding to the positions of the squares on the computer screen). Then in the final block, participants again saw a pseudorandom sequence. Participants' reaction times (RT) for correct responses were the primary dependent variable, and, in particular, participants' rebound scores (Kidd, 2012) were used to assess individual differences in procedural learning abilities. The rebound score is computed by subtracting participants' RTs in the final patterned block from their RTs in the final pseudorandom block. RTs generally decrease during training. However, such decreases could be the result of practice rather than the result of procedural learning. To factor out practice effects on RTs, the final pseudorandom block acts as a control. In healthy populations, RTs are generally slower on the final pseudorandom block than on the final patterned block. The size of this difference, or rebound score, measures how much of the RT speed-up was due to the learning of the patterned sequence.

After completing the SRT task, the participants were asked whether they noticed a pattern. If a participant responded in the affirmative, s/he was asked to generate the sequence with the gamepad by pressing the buttons in what they thought was the correct order until they produced 10 items. The computer recorded these responses, and they were subsequently analyzed. None of the participants were able to generate more than a single correct trigram in the production task. While this does not preclude the task from being sensitive to explicit knowledge, it does indicate that participants had low levels of awareness of the patterns at best.

3.3. Semiartificial language paradigm

3.3.1. Exposure phase stimuli

The experiment employed the semi-artificial language paradigm in which words from the participants' native language were placed into the syntactic structures of another language (cf. Rebuschat, 2008; Rebuschat & Williams, 2012). This method circumvents the need for vocabulary pre-training and allows researchers to more easily misdirect participants about the nature of the exposure phase, thereby reducing the likelihood that participants will engage in intentional, strategic learning of the target structures. This study used the same stimuli as detailed in Hamrick (2013, 2014b). Participants were exposed to English words placed into three syntactic structures derived from Persian (labeled A, B, and C), illustrated in Table 1. Participants read 32 “core” sentences rotated around the three training structures for a total of 96 exposure phase sentences. Participants were exposed to each core sentence three times, once in each target structure with no differences in their lexical (word forms) or compositional-semantic (meaning) content. The details of these stimuli are elaborated in Hamrick (2013, 2014b).

Table 1
Syntactic structures and an example core sentence placed in each structure. Structures A, B, and C were used in the exposure phase for the experimental group.

Label	Syntactic structure	Example
A	TEMPORAL PHRASE — SUBJECT — PREPOSITIONAL PHRASE — OBJECT — VERB	Earlier today the farmer at the market tomatoes sold.
B	TEMPORAL PHRASE — SUBJECT — OBJECT — PREPOSITIONAL PHRASE — VERB	Earlier today the farmer tomatoes at the market sold.
C	TEMPORAL PHRASE — VERB — SUBJECT — PREPOSITIONAL PHRASE — OBJECT	Earlier today sold the farmer at the market tomatoes.

3.3.2. Recognition task stimuli

The aim of the recognition task was to isolate an effect of memory for syntax beyond any contributions of lexical and semantic information. To achieve this, participants were instructed to discriminate old (previously seen) from new (previously unseen) sentences. Crucially, the terms “old” and “new” are relative in that they only describe the old-new status of syntax. Because the recognition task consisted only of core sentences (i.e., words and meanings) from the exposure phase, all recognition task sentences were equally old in the sense that all participants had read them before. That is, all participants had read the same words and compositional semantic meanings of all the sentences during the exposure phase. Recognition task items only differed in whether they followed the three “grammatical” Persian syntactic structures (old items) or “ungrammatical” structures (new items; see Hamrick, 2013 for a complete stimulus list). Put simply, half of the recognition task sentences were exactly the same in every way as in the exposure phase, while the other half were only the same in terms of their lexical and semantic content, but had different syntactic structures. Consequently, participants could only discriminate old from new sentences based on whether those sentences had been seen in the exact target syntactic structures from the exposure phase. Although the crucial factor in the recognition task was the “grammaticality” of the sentences, the recognition task was used instead of a conventional GJT, because previous research provided evidence of learning in the recognition task but not the GJT, making the former a more sensitive measure in this context (Hamrick, 2013, 2014a, 2014b). The recognition task contained 12 items. Half were core sentences from the first 18 exposure trials and half were core sentences from the final 18 exposure trials. In keeping with previous versions of this task, this procedure ensured that recognition performance was not just for recently seen items. Core sentences used in the recognition memory test were only used once each in order to minimize interference effects across test items due to lexical and/or semantic overlap.

3.3.3. Semi-artificial language procedure

Participants were tested individually in a quiet laboratory. They were told that they were participating in a study about meaning comprehension when reading scrambled sentences. Participants were instructed to read each sentence for meaning as though they were reading a book, article, or blog. After reading each sentence the computer prompted participants to indicate how easy or difficult it was to read that sentence on a scale from 1 (very easy) to 6 (very difficult). Each number corresponded to a labeled Cedrus button-box (RB-730). Sentences were presented using a self-paced non-cumulative moving window design in Superlab Pro 4.5. Sentences were segmented at syntactic category boundaries (e.g., Yesterday | Charlie | at the supermarket | milk | bought), and each button press corresponded with the presentation of a new syntactic category constituent. The exposure phase consisted of 96 trials (one per sentence). Each trial consisted of the presentation of a fixation cross, which remained on the screen until participants were ready to begin reading the next sentence. Participants pressed the designated button to advance through the sentence and then indicated how easy or difficult it was to read the sentence. Sentences were presented in random orders for each participant. Participants were not informed that there would be any kind of test after the exposure phase nor that there was anything to learn. The exposure phase took approximately 20 min to complete on average.

After the exposure phase, participants were instructed to read more sentences, but this time they would be asked to indicate whether or not they had seen each sentence before by indicating whether a sentence was the same or different via pushing assigned buttons on the response

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[4] One block equals 60 trials.

pad. Participants were also told that half of the test sentences would be old (i.e., exactly the same as the sentences they just read) and the other half would be new (i.e., not exactly the same as the sentences they just read). Sentences in the recognition task were presented using the same self-paced non-cumulative moving window procedure. On average, the recognition task took five minutes to complete. No feedback was provided on these tasks. This task constituted the immediate measure of syntactic learning. Participants then completed the same recognition task approximately after a period of no exposure ($M = 2$ weeks, range: 1–3 weeks), which constituted the delayed measure of syntactic learning (and retention). Participants did not practice the task or have any exposure to sample sentences before the delayed retention measure.

3.4. Overall procedure

Participants were asked to complete the LLAMA-B, SRT task, and the semi-artificial language task in the first session. The order of the tasks was counterbalanced across participants. After session one, participants were invited back to be debriefed about the study. Upon arrival for the delayed session, participants were asked if they would be willing to take the same recognition test again, and all agreed. After the recognition test, participants' were debriefed about the purpose of the experiment.

4. Results

4.1. Recognition task

Recognition task performance was assessed by computing d' scores for each participant on both the immediate and delayed recognition tests (Table 2). A paired-samples t-test on participants completing all tasks ($n = 18$) revealed that recognition d' scores on the immediate test were significantly higher than on the delayed test, $t(17) = 2.59$, $p = .02$, $r = .53$, 95% CI [0.11, 1.07]. One-sample t-tests on participants who completed all tasks revealed that d' scores were significantly above zero on the immediate recognition test, $t(17) = 4.33$, $p < .001$, but not on the delayed recognition task, $t(17) = 1.59$, $p = .12$.

4.2. LLAMA-B

The overall results show that mean performance on the LLAMA-B was significantly greater than chance (5% accuracy) for all participants, $t(30) = 13.45$, $p < .001$, and for the subset that completed all the tasks, $t(17) = 12.92$, $p < .001$.

4.3. SRT task

Before computing the results for the SRT task, participants' incorrect responses were first discarded, leaving 99.06% of the data for analysis. Analyses were conducted by first log-transforming the RT values. Fig. 1 shows that participants were generally faster at responding to the patterned blocks of the SRT task (B1 through B4) than they were on the pseudorandom blocks (R1 and R2). To investigate whether learning occurred at the group level in the SRT task, a repeated measures ANOVA on log-transformed RT for only the participants who completed all tasks was conducted with Block as a within-subjects factor. The results revealed a significant effect of Block, $F(5, 85) = 24.1$, $p < .001$, $\eta_p^2 = .59$[5]. To assess whether there was a significant slow-down effect when participants reached the final pseudorandom block R2, RTs for blocks B1 through B4 were compared with RTs for block R2. Bonferroni-corrected post-hoc paired-sample t-tests (alpha revised to $p < .0125$) revealed that participants were significantly slower on block R2 than blocks B2, $t(17) = 7.39$, $p < .001$, $r = .76$, 95% CI [0.05, 0.10], B3, $t(17) = 5.30$, $p < .001$, $r = .62$, 95% CI [0.05, 0.11], and B4, $t(17) = 6.89$, $p < .001$, $r = .74$, 95% CI [0.06, 0.12], but not B1, $t(17) = 2.07$, $p = .054$, indicating that the sample as a whole learned the sequence. For comparability with previous studies (e.g., Kidd, 2012), the difference score between the final patterned block B4 and the final pseudorandom block R2 was considered as a rebound score, serving as the behavioral measure of procedural memory abilities.

Table 2
Descriptive statistics for all participants ($n = 30$) and those who completed all tasks ($n = 18$) on the recognition task and the LLAMA-B.

		M	*SD*	*SE*	95% CI
Immediate	All	1.03[**]	1.05	0.19	0.63, 1.43
	Completed	0.89[**]	0.88	0.21	0.46, 1.33
Delayed	All	0.33[*]	0.78	0.17	−0.03, 0.70
	Completed	0.30	0.81	0.19	−0.09, 0.71
LLAMA-B	All	52.76[**]	19.11	3.54	45.59, 60.03
	Completed	53.89[**]	16.04	3.78	45.91, 61.87

[*] Significance from zero, $p < .07$.
[**] Significance from zero, $p < .001$.

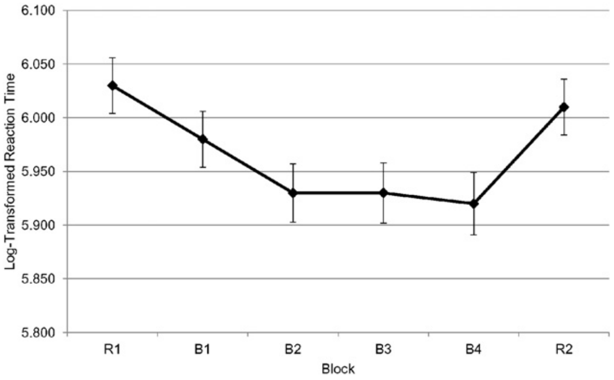

Fig. 1. Mean log-transformed reaction times across each block of the serial reaction time task. Error bars represent +/− 1 SE.

4.4. Correlations between memory and syntax measures

To address the primary research question, whether there is a relationship between declarative and procedural memory abilities and L2 syntax learning under incidental conditions, scores on the immediate recognition task were first analyzed by comparing participants' d' scores on the immediate recognition task with their LLAMA-B accuracy scores and SRT task rebound scores. Pearson's correlations (two-tailed) revealed a significant correlation between participants' d' scores on the immediate recognition task and their accuracy on the LLAMA-B ($r = .41$, $p = .03$) but not their SRT task rebound scores ($r = -.20$, $p = .29$). Thus, the results show a relationship between declarative memory abilities, but not procedural memory abilities, and syntax learning under incidental conditions in an immediate test. When analyses are restricted to only the eighteen participants who completed all tasks, the relationships between immediate recognition and LLAMA-B ($r = .21$, $p = .41$) and the SRT task rebound score ($r = .01$, $p = .94$) cease to be statistically significant (Table 3).

In order to determine whether there is a relationship between declarative and procedural memory abilities and performance on a delayed measure of syntax learning under incidental conditions, participants d' scores on the delayed recognition task was compared with their LLAMA-B accuracy scores and SRT task rebound scores, this time using the more conservative Kendall's *tau* correlation coefficient, due to the smaller sample size and four ties in scores. The results revealed a significant correlation between participants' SRT task rebound scores and retention of incidentally learned L2 syntax ($\tau = .43$, $p = .01$),

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[5] The same analyses conducted on participants who completed the SRT ($n = 29$) revealed the same pattern of significant results.

Table 3
Correlations between performance on all tasks.

	Immediate test	Delayed test	LLAMA-B	SRT task
Immediate test	–			
Delayed test	0.8[a]	–		
LLAMA-B	.41[b,*]	.18[a]	–	
SRT task	−.20[b]	.43[a,**]	−.09[b]	–

[a] Kendall's tau.
[b] Pearson's *r*.
* $p < .05$.
** $p < .01$.

but not between their LLAMA-B accuracy and retention of incidentally learned L2 syntax ($\tau = .18$, $p = .29$). Thus, the results show that after weeks of no exposure there is a relationship between procedural memory abilities, but not declarative memory abilities, and the retention of syntax learned under incidental conditions (Fig. 2). However, low power due to participant attrition and the statistically non-significant retention effect in the recognition task warrant caution in interpreting these results.

5. Discussion

The present study was motivated by the fact that individual differences in declarative and procedural memory have previously been shown to correlate with L2 learning, but only under learning conditions in which participants were told that their goal was to learn (e.g., Morgan-Short et al., 2014). Given that working memory abilities have been shown to correlate with L2 learning more under intentional learning conditions (e.g., Brooks et al., 2006; Kempe & Brooks, 2008; Tagarelli et al., 2011, 2015) than incidental learning conditions (e.g., Grey et al., 2015; Reber et al., 1991; Robinson, 2005; Tagarelli et al., 2011, 2015), this study aimed to address whether this would also hold true for the relationships between declarative and procedural memory and L2 grammar learning.

Two research questions were posed. The first asked whether individual differences in declarative/procedural memory abilities would correlate with L2 syntactic development under incidental learning conditions. The results indicated that L2 syntax learning under incidental conditions was positively correlated with declarative memory abilities and negatively correlated with procedural memory abilities in an immediate test. This result is consistent with the predictions of declarative/procedural models of language (e.g., Paradis, 2004, 2009; Ullman, 2001, 2005, 2015), which suggest that early phases of L2 grammar learning rely on declarative memory. This result is also consistent with previous findings linking declarative memory and early L2 grammar learning under more intentional conditions where participants are told that they would be learning an artificial language (e.g., Carpenter, 2008; Morgan-Short et al., 2014; Morgan-Short et al., 2015). However, it should be noted that this relationship was only found when all participants were analyzed, and the correlation between declarative memory abilities and syntax learning was not statistically significant when analyses were restricted to the 18 participants who completed all tasks.

The second research question asked whether a period of no exposure would affect any relationships between declarative/procedural memory abilities and L2 syntactic development. The results revealed that after 1–3 weeks of no exposure, there was a relationship between procedural memory abilities, but not declarative memory abilities, and the retention of syntax learned under incidental conditions. This result is consistent with one interpretation of Morgan-Short, Finger, et al. (2012) who found that months of no exposure revealed a shift in the underlying mechanisms supporting L2 grammar. Overall, the results of the present study provide the first evidence, to the author's knowledge, that individual differences in declarative and procedural memory correlate with L2 learning under incidental conditions.

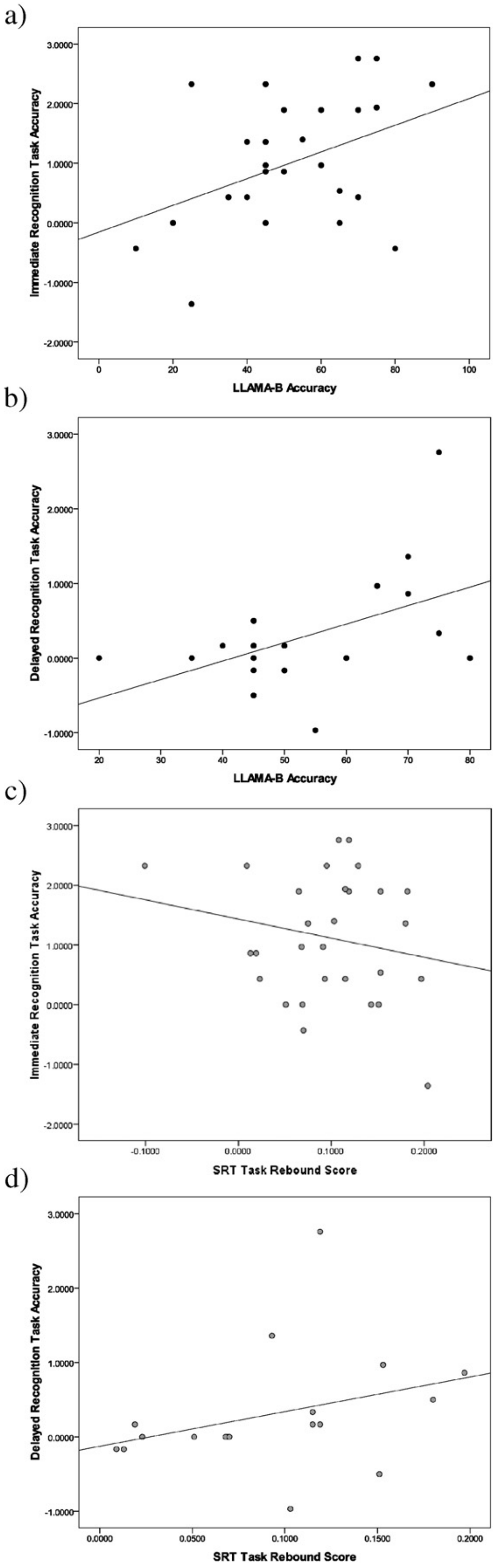

Fig. 2. Scatterplots showing the distribution of LLAMA-B accuracy and d' scores on the immediate recognition test (a) and delayed recognition test (b) and SRT task rebound scores and d' scores on the immediate recognition test (c) and delayed recognition test (d).

The present study has at least two theoretical implications. First, the fact that both declarative and procedural memory abilities correlated with L2 syntax learning under incidental conditions suggests that, unlike working memory capacity, individual differences in these memory systems constrain learning outcomes in both incidental and intentional learning conditions. Thus, the results are consistent with the notion that individual differences in these memory abilities correlate with language learning in general and may not be a byproduct of specific learning conditions. Moreover, recall that Morgan-Short et al. (2014) also found that declarative memory abilities predicted L2 grammar learning in early, but not later, phases of learning under intentional conditions, while the opposite was true for procedural memory abilities. Together, the results of Morgan-Short et al. (2014) and the present study reveal relationships between declarative and procedural memory abilities and L2 grammar learning that are similar in direction, timing, and size. This is all the more impressive when one considers how different the two studies are: they differ in terms of the memory measures used, the artificial languages used, the testing measures used, and in terms of the learning conditions themselves (intentional in the sense that learners knew they were supposed to learn the language in Morgan-Short et al., 2014, and incidental in the present study). Thus, the results of these two studies provide converging evidence indicating that declarative and procedural memory share some common underlying mechanisms with L2 learning abilities, and these common mechanisms are affected by time and operate under both incidental and intentional learning conditions.

The present study also suggests that the mechanisms supporting L2 syntax abilities may differ after a period of no exposure. This result is consistent with one interpretation of previous research, again using the Brocanto2 paradigm. Morgan-Short, Finger, et al. (2012) found that after an initial learning phase followed by months of no exposure, adult L2 learners developed more native-like event-related potential (ERP) signatures of grammar processing. The combined results show that increased relationships with procedural memory and increased native-like processing both occur with time delays. This may reflect a common underlying mechanism, if we assume that native-like ERP signatures of grammar processing are linked to procedural memory. However, this conclusion may be premature, since it remains to be seen whether the ERP signatures of native-like grammar processing are related to procedural memory. Moreover, the numerous differences between these studies prevent strong conclusions. For example, unlike the Morgan-Short, Finger, et al. (2012) study, the present results revealed no significant retention in L2 syntax abilities, possibly due to less exposure. Thus, it will be important to see if the same correlation would occur at higher proficiencies persisting over longer delays (as was reported in Morgan-Short, Finger, et al., 2012).

5.1. Limitations and future research

Several limitations in the present study warrant caution in generalization. First, there are the obvious limitations in sample size. Both this study and previous studies (e.g., Morgan-Short et al., 2014) have found evidence for relationships between declarative/procedural memory abilities and L2 learning but with small sample sizes. When sample sizes are small, adding or subtracting one or two participants can substantially affect the statistical significance of the results. Indeed, the effects of sample size are clearly visible in this study, particularly when it comes to the relationship between declarative memory and syntax learning in the immediate test. Declarative memory correlated with syntax learning on an immediate test, but only when all participants were included in the analysis. When the analysis was restricted to the 18 participants who completed the task, the correlation was no longer statistically significant. Consequently, the present study does not show as robust a shift from declarative to procedural memory as previous work. It remains to be seen whether this is a byproduct of sample size or whether it reflects a more complex picture. More research is needed with larger samples.

Second, there are a number of limitations to the semi-artificial language paradigm that have been documented elsewhere in detail (Hamrick, 2013, 2014a, b). As with artificial languages, there are limitations in the extent to which they capture natural language phenomena. Future work necessitates triangulating language learning and individual differences in memory using by using natural languages in addition to artificial and semi-artificial ones.

Third, it is possible that the study was biased in favor of correlations with declarative memory. Given that participants were predominantly female, and given the link between estrogen and verbal declarative memory abilities, it is possible that declarative memory played more of a role in this sample than it might in a more balanced or all-male sample. Likewise, the use of a recognition task itself may be seen as encouraging participants to recall episodic memories. Indeed, such tasks are classical measures of declarative memory. However, given that similar results have been obtained with different paradigms (e.g., GJT in Morgan-Short et al., 2014), it is unlikely that the correlations between declarative memory and language abilities found here are exclusively a byproduct of the recognition task.

The present study was also limited in its operationalization of L2 syntactic knowledge. Receptive recognition measures are sensitive measures to some low level of knowledge, but obviously do not say anything about the more robust abilities necessary for production. It remains to be seen whether L2 syntax learning under incidental conditions gives rise to production and to what degree production abilities would also correlate with individual differences in memory abilities.

6. Conclusion

This study examined whether learning L2 syntax under incidental conditions was related to individual differences in declarative and procedural memory abilities. Learning L2 syntax under incidental conditions was positively correlated with declarative learning abilities immediately after a brief exposure phase. After a period of no exposure, however, procedural memory abilities predicted the retention of incidentally learned L2 syntax. These findings indicate that individual differences in declarative/procedural memory abilities can predict L2 learning under incidental conditions. These findings are consistent with theories of L2 learning that posit roles for declarative and procedural memory at different phases of L2 syntactic development. When considered with previous research, the emerging pattern suggests that individual differences in declarative and procedural memory may correlate with L2 grammar learning in both intentional and incidental learning conditions.

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