

The Role of Procedural Memory in Adult Second Language Acquisition

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Abstract

This study examined the role of procedural memory in adult second language (L2) development. Participants were trained on an artificial language under either explicit or implicit conditions. Development in the L2 was assessed by grammar tests at two time points. Measures of procedural memory were administered and were used to create high and low procedural groups. Results revealed an advantage in L2 development for learners with high procedural memory when trained in the implicit condition. Overall, this study suggests that procedural memory may be an important factor in adult L2 development but its role may differ under different learning contexts.

Keywords: Adult second language acquisition; Procedural memory; Syntax

Introduction

A relatively recent line of investigation in second language (L2) research has focused on the role of different types of domain general memory systems in adult L2 acquisition of grammar. Initially research focused on the role of working memory (e.g., Robinson, 2003; Williams, 2012) and now has also begun to examine the role of declarative and procedural memory (Carpenter, 2008; Morgan-Short, Faretta-Stutenberg, Brill-Schuetz, Carpenter, & Wong, 2014). Theories put forth by Ullman (2001, 2004, 2005), Paradis (1994, 2004, 2013), and DeKeyser (2007) have posited that these two types of long-term memory have an important role in language learning and claim that success at advanced stages of L2 development may depend on procedural memory in particular. This claim has received some initial empirical support (Carpenter, 2008; Ettlinger, Bradlow, & Wong, 2012; Morgan-Short, Faretta-Stutenberg, et al., 2014), but the nature of the relationship between procedural memory and L2 development is not entirely clear and is further examined in the present study.

Although there are differences among the declarative/procedural-based theories of L2 acquisition (DeKeyser, 2007; Paradis, 1994, 2004, 2009, 2013; Ullman, 2001, 2004, 2005), each theory independently posits that as L2 learners gain exposure, experience, and proficiency with the L2, they come to rely on procedural memory or knowledge, which is generally understood to reflect memory for skills and habits and is a specific subtype of nondeclarative, implicit memory (Squire & Zola, 1996). This idea has already received some support in behavioral studies. For example, Morgan-Short, Faretta-Stutenberg, et

al. (2014) examined whether individual differences in procedural memory predicted performance on an assessment of L2 syntax (word order) at the end stages of learning an artificial language. Procedural memory was assessed using a composite score across two computerized measures of procedural memory: the Tower of London (TOL; Uttner et al., 2004) and the dual-task version of the Weather Prediction Task (WPT; Knowlton, Squire, & Gluck, 1994). Results confirmed that higher procedural memory scores were associated with better performance on an L2 judgment task assessing knowledge of word order. Similarly, Ettlinger et al. (2012) examined the role of procedural memory in the learning of simple and complex, artificial L2 morphophonological rules. Procedural memory was assessed using the TOL task, and results showed that participants who performed better on the TOL also evidenced a mastery of the simple rules at final test.

Although these studies lend initial support to the idea of procedural memory being involved in L2 acquisition at later stages, it should be noted that for both of the studies mentioned above, learners were exposed to the L2s under implicit training conditions, which were designed to reflect immersion-like contexts, where explicit rule explanation may not be available. However, not all adult L2 learners are exposed to an L2 under such contexts. Many learners acquire their L2 in classroom contexts where there is frequent, explicit instruction of grammatical rules. Evidence suggests that different learning contexts may have an effect on both L2 learning outcomes (Norris & Ortega, 2000) and on the neurocognitive bases for such outcomes (Morgan-Short, Finger, Grey, & Ullman, 2012; Morgan-Short, Sanz, Steinhauer, & Ullman, 2010; Morgan-Short, Steinhauer, Sanz, & Ullman, 2012). Thus it is important to consider, the role that procedural memory may play in different types of L2 contexts or training conditions. Indeed, one may expect an aptitude-treatment interaction (e.g., Robinson, 2001; Snow, 1991), where procedural memory ability (aptitude) may play a larger role under implicit training conditions as compared to explicit training conditions (treatment).

One previous study has provided some preliminary evidence regarding the role of procedural memory in adult L2 development across different learning contexts. Carpenter (2008) examined the role of procedural memory in the development of word order proficiency at the end stages of learning an artificial L2 under either an explicit training condition, where learners were exposed to L2 forms

along with grammatical rules and explanations, or an implicit training condition, where learners were exposed to the L2 but were not provided with any grammatical rules or explanations. Procedural memory was assessed with the dual-task WPT (Knowlton et al., 1994). Results showed that procedural memory did not play a role for explicitly trained learners but accounted for higher levels of development for a subset of implicitly trained learners on end-of-training grammar assessments.

In sum, emerging evidence lends support to the theoretical claim that procedural memory plays a role at advanced stages of L2 acquisition. However, such results merit replication and extension and, in general, would be more robust and informative if research took the following approach: First, studies should use more than one measure of procedural memory in order to more adequately capture this construct (Cronbach & Meehl, 1955; Messick, 1975). Second, comparisons of the role of procedural memory across explicit and implicit training conditions would inform theoretical perspectives in regard to whether procedural memory plays a role only under certain conditions or whether its role is more universal. The current study takes such an approach.

Methods

Participants

Twenty-six students (18–24 years old; 16 female) from a large midwestern university were recruited either through a psychology course subject pool or through flyers, and received class credit or monetary compensation, respectively, for participation. Selection requirements limited participants to those who had no hearing, learning, or speaking impairments, and to those who were native speakers of English. Participants were pseudo-randomly assigned to either the explicit or the implicit training condition (see below). Previous experience with L2 was equally matched between the two groups.

Artificial Language

The artificial language learned by participants was Brocanto2 (Morgan-Short, Faretta-Stutenberg, et al., 2014; Morgan-Short, Finger, et al., 2012; Morgan-Short et al., 2010). In contrast to many artificial grammar learning paradigms, the artificial language Brocanto2, modeled after the artificial language Brocanto (Friederici, Steinhauer, & Pfeifer, 2002), is based on universal requirements of a natural language and is fully productive and meaningful. Previous research with these artificial languages has shown that learners evidence processing patterns that are similar to those found in natural language processing (Friederici et al., 2002; Morgan-Short, Finger, et al., 2012; Morgan-Short et al., 2010; Morgan-Short, Steinhauer, et al., 2012), suggesting the use of Brocanto2 in the current study has ecological validity in regard to L2 acquisition. At the same time, the use of the artificial language allows learners to reach high proficiency in a shortened amount of time and

allows for control over confounding variables as compared to natural languages.

Brocanto2 consists of 14 words: four nouns (*pleck, neep, blom, vode*), two adjectives (*troise/o, neime/o*), two articles (*li/u*), four verbs (*klin, nim, yab, praz*) and two adverbs (*noyka, zayma*) (see Table 1 for full sentence). The grammatical structure of this language follows a similar pattern to that of Romance languages and not to English. Whereas English follows a subject-verb-object order, Brocanto2 follows a subject-object-verb order. Each noun (e.g., *blom*) is either masculine or feminine and can be followed by a gender-specific adjective describing the shape of the game piece (e.g., *neimo*). The noun or adjective is then followed by a gender-agreeing article (i.e., *lu*). The initial, subject noun phrase can be followed either by an intransitive verb (e.g., *klin*) or by a direct object noun phrase (e.g., *neep neime li*) and a transitive verb (e.g., *praz*). Verbs can be followed by an adverb indicating what direction the pieces should move. Participants learned this artificial language in order to play a computer-based game in which the movement of tokens is described by the language (see Figure 1).

Table 1: Sample Brocanto2 sentences.

Grammatical:					
<i>Blom</i>	<i>neimo</i>	<i>lu</i>	<i>neep</i>	<i>neime li</i>	<i>praz.</i>
Blom-piece	square	the	neep-piece	square the	switch.
“The square blom-piece switches with the square neep-piece.”					
Violation:					
<i>Blom</i>	<i>*nim</i>	<i>lu</i>	<i>neep</i>	<i>neime li</i>	<i>praz.</i>
Blom-piece	capture	the	neep-piece	square the	switch.
“The capture blom-piece switches with the square neep-piece.”					

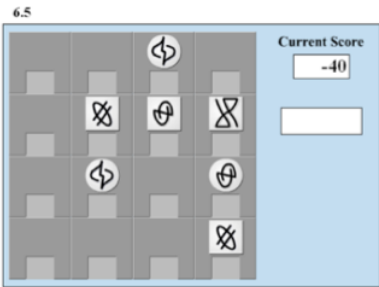


Figure 1: Screen shot of Brocanto2 computerized board game.

Language training and practice. On the first and third day of the study, participants were engaged in either an explicit or implicit language training condition followed by practice.¹ The artificial language training phase lasted approximately 13 minutes regardless of the condition. In the explicit training condition, participants were auditorily

¹ Note that we do not assume that explicit and implicit training leads exclusively to explicit and implicit learning, respectively.

presented with the specific rules and examples of phrases and sentences in Brocanto2. In the implicit training condition, no rules or explanations were given and instead participants received repeated, aural examples of the language that ranged from simple noun phrases to complete sentences. At no point in the training did any participant see written examples of the language.

After completing the training portion of the language, participants continued on to the practice modules. Practice consisted of using Brocanto2 to play a computer-based board game (see Figure 1). Participants either heard sentences and made the corresponding move on the game board (comprehension) or saw a move and orally described it (production). A total of 20 practice modules were presented over the course of the study (10 production and 10 comprehension), with 20 novel sentences presented in each module for a total of 400 practice items.

Assessment. On the second and final day of the study, assessments were administered. Participants were given a grammaticality judgment task (GJT) to measure their knowledge of the language. The GJT consisted of 120 novel sentences that were presented auditorily. Participants were asked to judge whether each sentence was correct or incorrect and responded by pressing either the right or left mouse button. In this task, participants heard 60 grammatical and 60 ungrammatical sentences that contained word order violations.² Violations were created by replacing one word from each of the 60 correct sentences with another word from one of the five word categories (see Table 1) so that the new sentence violated the word-order rules of Brocanto2 (Morgan-Short et al., 2012). The distribution of the violations was as even as possible across all word types (nouns, verbs, etc.) and one verb was omitted to control for sentence length (between 5 and 8 words). Violations never occurred on the first or final word and violation position among words was as evenly distributed as possible. The 120 sentences were broken down into two blocks of 60 (half ungrammatical) sentences, which were administered in a counterbalanced order so that participants received different versions on the two assessment days.

Procedural Memory Measures

Two measures of procedural memory were administered over the course of the study: the Alternating Serial Reaction Task (ASRT; Howard & Howard, 1997) and the WPT (Knowlton et al., 1994).

The first measure of procedural memory was the ASRT (Howard & Howard, 1997). The ASRT, like the original SRT, uses sequence learning that has previously been

regarded as implicit or procedural in nature (Deroost & Soetens, 2006). In this computerized version of the task, participants watched circles on the screen fill in with black dots. Participants responded to these targets by pressing the corresponding key on the keyboard: They were instructed to press the key as soon as the circle was filled in and to respond as quickly and accurately as possible using their right and left middle and index fingers (each finger was assigned to a particular key on the keyboard). There was an embedded pattern that was presented in trials that alternated with random trials. For example, if the pattern was 1234, the circle farthest to the left would fill in, followed by a random circle, followed by the second circle from the left, etc. Therefore, the sequence of targets would be 1r2r3r4r. Reaction times were measured and accuracy rates were recorded; improvement in reaction time for patterned trials versus random trials was the measure of procedural memory used in analyses.

The second measure of procedural memory was the dual-task version of the WPT (Knowlton et al., 1994; Poldrack & Packard, 2003). The WPT is a probability-based learning task where participants are presented with various geometrical patterns on cards to determine the weather forecast (sunshine or rain). The particular arrangement of patterns on each card was associated with a particular probability of rain. These cards were presented using E-Prime v2.0 and there were a total of 320 trials divided into eight blocks. Neither a sunshine nor a rain stimulus occurred more than four times in a row. After a response was given, the correct response was shown. The secondary task in the WPT involved the counting of high tones during a trial. Therefore, every trial consisted of participants making a sun/rain judgment and keeping a running total number of high tones, which were interspersed with low tones. This was a distracter task designed to increase the reliance on procedural memory and reduce the development of explicit information. Accuracy and reaction time for the primary task (predicting weather) were the measures that were examined as markers for successful procedural learning. However, weather prediction accuracy on the final block (block 8) of the dual-task condition was used for analyses.

Procedure

This was a six-hour study that took place over four days with a maximum of three days in between sessions. On day one, participants completed a language background questionnaire followed by either explicit or implicit artificial language training and practice modules 1–10. Day two consisted of either the ASRT or other cognitive measures, and the first administration of the GJT (GJT1). Day three consisted of the second training session, practice modules 11–20, and the WPT. On the final day participants completed a second administration of the GJT (GJT2) and either the ASRT or other cognitive measures. Except for the WPT, the cognitive tasks and the GJT version order were counterbalanced across participants (see Figure 2).

² Word order violations as opposed to other possible types of violations, e.g., gender agreement, were examined in the current study because word order seems to be learned more successfully and more quickly than other structures (Morgan-Short, 2007). Given that the current study does not provide extended training and practice as in previous Brocanto2 studies, learning effects are more likely to be evidenced with this structure than with other structures.

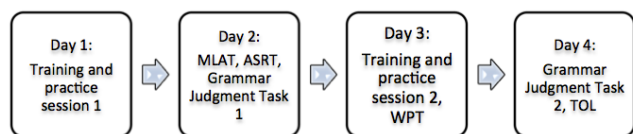


Figure 2: Overview of study design.³

Results

First, performance on the GJT1 and GJT2 was compared to establish whether there was significant language development from the first grammar assessment to the second grammar assessment and that this was the pattern for participants in both training conditions. To assess this, a 2 (Training Condition: implicit vs. explicit) \times 2 (Time: GJT1 vs. GJT2) repeated measures ANOVA was conducted. The results showed that there was a significant difference between GJT assessments, with participants scoring higher on the GJT2, $F(1, 24) = 28.24, p < .001$, (GJT1: $M = .78, SD = .87$, GJT2: $M = 1.74, SD = 1.27$). Alternately, there were no differences based on Training Condition, $F < 1, ns$, and no interaction between Time and Training Condition. Evidence for learning in each of the assessments of procedural memory was also verified through statistical analysis (ANOVAs). For the ASRT, participants performed better on Block 10 vs. Block 1, $F(1, 25) = 8.05, p < .01$; they also performed better on pattern vs. random trials, $F(1, 25) = 4.58, p < .05$. For the WPT, a paired-samples t -test showed that participants performed better on the final block of the dual-task WPT compared to the first block, $t(25) = -2.21, p < .05$.

Next, the measures of procedural memory were used to create a composite score using the z-scores of the ASRT and WPT. The procedural composite score was used in the subsequent analyses. A median split based on this score divided learners into high and low procedural memory ability groups and served as the bases for subsequent analyses.

The primary research question explored the role of procedural memory in L2 development across differing training conditions. More specifically, we examined how procedural memory ability influenced performance on the grammar assessment, and if variable patterns of performance under different training emerge. To address

this question, a 2 (Group: implicit vs. explicit) \times 2 (Procedural Memory: high vs. low) \times 2 (Time: GJT1 vs. GJT2) repeated measures ANOVA was conducted. The results showed a significant main effect for Time, $F(1, 22) = 35.80, p < .001, \eta_p^2 = .62$, reflecting higher performance at GJT2 when compared to GJT1 (GJT1, $M = .78, SD = .87$; GJT2, $M = 1.74, SD = 1.27$). Results showed a trending effect for Procedural Memory Ability, $F(1, 22) = 3.87, p = .06, \eta_p^2 = .15$, reflecting better performance for the high group compared to the low group (GJT1: high, $M = 1.08, SD = 1.02$; low, $M = .47, SD = .57$; GJT2: high, $M = 2.19, SD = 1.20$; low, $M = 1.29, SD = 1.21$). There was no effect of training group, $F < 1.0, ns$. Each of these effects was qualified by a Group \times Procedural Memory Ability \times Time interaction, $F(1, 22) = 5.90, p < .05, \eta_p^2 = .21$.

Subsequent analyses were conducted in order to reveal the source of the interaction. These analyses revealed a Time \times Procedural Memory Ability interaction in the implicit training group, $F(1, 11) = 15.59, p < .01, \eta_p^2 = .59$, but no significant interaction for the explicit training group. The interaction in the implicit training condition was driven by an effect for Procedural Memory Ability, $F(1, 11) = 11.42, p < .01$, at GJT2 but not at GJT1 (see Figures 3 and 4). The effect was such that participants with high procedural memory ability performed better than participants with low procedural memory ability in the implicit training condition. All other follow-up comparisons did not yield significant results.

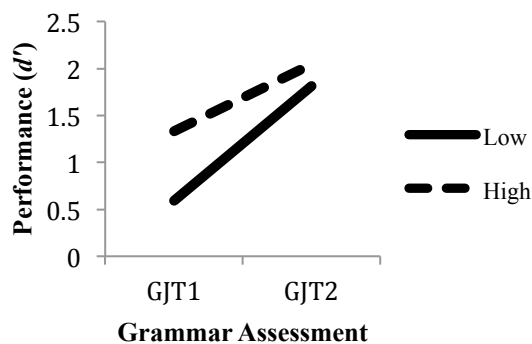


Figure 3: Language performance in explicit training condition for low vs. high procedural memory ability.

³ The other cognitive measures used in this study were the TOL (Unterrainer et al., 2004) and part V of the Modern Language Aptitude Test (MLAT; Carroll & Sapon, 1959). The computerized TOL was included based on previous studies (Ettlinger et al., 2012; Morgan-Short, Faretta-Stutenberg et al., 2012) and was used in order to more fully capture the underlying construct of procedural memory. However, upon analysis, the TOL did not demonstrate a stable relationship to other measures of procedural memory and was not included in the analyses reported below. The MLAT V was used as a measure of declarative memory but is not included in the analyses below because it is not related to the current research questions.

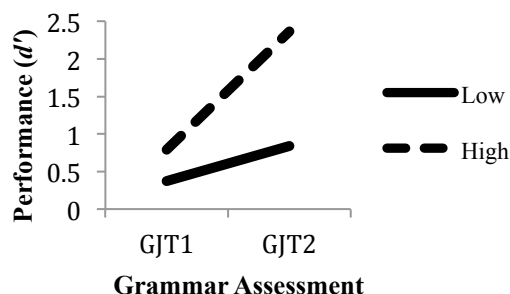


Figure 4: Language performance in implicit training conditions for low vs. high procedural memory ability.

Discussion

Overall, the results of this study are consistent with a general role for procedural memory in adult L2 development, as suggested by the trending main effect for procedural memory ability. Furthermore, the results revealed an interaction with procedural memory ability, training condition, and stage of development, suggesting that the role of procedural memory may differ for different L2 training conditions and may change over time or with increasing proficiency. More specifically, participants with high procedural memory ability performed better than participants with low procedural memory ability on final grammar assessments when they had been trained under implicit conditions. Thus higher procedural memory ability led to higher levels of L2 development, particularly under implicit conditions. Indeed, it appears that high procedural memory ability paired with implicit training conditions produced an optimal learning context.

These findings are consistent with the results from the previous studies conducted by Carpenter (2008), Ettlinger et al. (2010), and Morgan-Short, Faretta-Stutenberg, et al. (2014), which showed that procedural memory ability predicted success in implicit language training conditions at later stages of L2 development. This study adds to the previous studies by expanding the measures of procedural memory and examining its influence across both explicit and implicit training conditions.

More broadly, the findings from this study also are consistent with the ideas posited by DeKeyser's Skill Acquisition Theory (2007), Paradis (1994, 2004, 2009, 2013), and Ullman's Declarative/Procedural (DP) Model (2001, 2004, 2005), all of which predict involvement of procedural memory at later, more proficient stages of language development. Specifically, the finding that performance on procedural memory tasks played a role in L2 development at later stages of learning but not at early stages, at least for implicitly trained learners, seems consistent with these predictions. However, the results also suggest that the theories must also account for why procedural memory appears to play a more significant role under implicit training conditions.

The results of this study more generally support the idea of aptitude-treatment interactions in L2 learning contexts (Robinson, 2001) in that procedural memory may be an important contributor to language learning specifically within implicit training conditions. Implicit training conditions are most similar to language immersion settings where learners are exposed to the language without rules or explanations. Therefore, it might be beneficial for late L2 learners with strong procedural memory to elect to study under immersion-based contexts either in the classroom or study abroad settings in order to maximize their L2 development potential.

While this study provides valuable new information about the role of procedural memory in adult L2 learning, the length of this learning study is one limitation that may affect the relationships found in the data. Ideally, participants would have been able to complete a greater number of practice modules to ensure that each participant reached a high level of proficiency (i.e., achieving 95% in consecutive modules). Adding a separate session of cognitive testing before participants begin any language training, rather than having cognitive testing intertwined with language training and assessment, would rule out any confounding influence that the artificial language training conditions may have had on cognitive test performance.

In future research, a replication of this study using multiple measures of both declarative and procedural memory would be informative in regard to the full set of predictions made by declarative/procedural theories of L2, i.e., that declarative memory plays a larger role at early stages of L2 development whereas procedural memory plays a larger role at later stages. Only the latter was tested here. In addition, it would be interesting to also examine whether similar relationships are evidenced for more complex linguistic systems as well as for first language acquisition.

In conclusion, this study showed that procedural memory may be an important factor in adult L2 development, consistent with predictions made by declarative/procedural theories of L2. Importantly, though, the findings suggest that the role of procedural memory may differ under different learning contexts. This may be considered evidence for exploring procedural memory as another individual difference in language acquisition for late (adult) learners. This study suggests that we may be able to better guide language development by assessing specific cognitive skills of the learner before assigning them to a particular mode of training. More generally, the results warrant further examination of the role of procedural memory as well as other domain-general memory systems in L2 acquisition.

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