Declarative and Procedural Memory as Individual Differences in Second Language Aptitude

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Abstract

Domain-general approaches to second language acquisition (SLA) have considered how individual differences in cognitive abilities contribute to foreign language aptitude. Here, we specifically consider the role of two, long-term, cognitive memory systems, i.e., declarative and procedural memory, as individual differences in SLA. In doing so, we define and review evidence for the long-term declarative and procedural memory systems, consider theories that address a role for declarative and procedural memory in L2 acquisition, discuss evidence in support of the claims that these theories make, and conclude with discussion of important directions and questions for future research on the role of declarative and procedural memory as individual differences in assessing L2 aptitude.

Declarative and Procedural Memory as Individual Differences in Second Language Aptitude

Research in second language (L2) aptitude addresses the components that together constitute aptitude, where aptitude is regarded as a latent construct or trait that predicts outcomes in L2 acquisition (Wen, Biedroń, & Skehan, 2017). Recent approaches to L2 aptitude have considered aptitude to be comprised of cognitive abilities (Ellis, this volume; Wen et al., 2017), including constructs such as attentional control and working memory (Robinson, 2007; Skehan, 2016; Wen, this volume). Thus, individual differences in these cognitive abilities would assumedly contribute to differing levels of L2 aptitude among individuals. An emerging line of research suggests that long-term memory may also serve as an individual difference factor in L2 learning. More specifically, declarative and procedural memory, both of which are domain-general, cognitive, long-term memory systems have been posited to play a role in L2 learning (DeKeyser, 2015; Paradis, 2009; Ullman, 2015), and individual difference research largely supports these claims (e.g., Antoniou, Ettlinger, & Wong, 2016; Faretta-Stutenberg & Morgan-Short, 2017; Hamrick, 2015; Morgan-Short, Faretta-Stutenberg, Brill-Schuetz, Carpenter, & Wong, 2014).

The current chapter considers the role of declarative and procedural memory in L2. First, we provide detailed definitions of declarative and procedural memory and knowledge, and then review three theoretical perspectives that posit that declarative and procedural memory contribute to L2 acquisition: Ullman (2015), Paradis (2009), and DeKeyser's Skill Acquisition Theory (DeKeyser, 2015). Subsequently, we provide a review of empirical evidence that examines whether declarative and procedural memory can account for individual differences in L2 learning, as would be predicted by the theoretical perspectives. Finally, we provide a discussion of future research directions in regard to the role of declarative and procedural memory in L2 and conclude that these long-term memory constructs should potentially be considered as components of L2 aptitude.

Long-term Memory Systems

Declarative Memory

Declarative memory is a memory system that supports the acquisition of facts and personal experiences (Cabeza & Moscovitch, 2013; Eichenbaum, 2011; Eichenbaum & Cohen, 2001; Henke, 2010; Morgan-Short, 2013a; Squire & Dede, 2015; Squire & Wixted, 2011; Squire & Zola-Morgan, 1991; Ullman, 2004; 2015; 2016). For example, declarative memory may support the learning of facts such as that the Chicago Cubs won the World Series in 2016 as well as the personal episodic experience of watching the championship baseball game. Declarative memory may be further described by a number of (neuro)cognitive characteristics. For one, knowledge in declarative memory may be explicit, in the sense of being accessible to conscious awareness. However, declarative memory also supports the learning of implicit information (Cabeza & Moscovitch, 2013; Henke, 2010; Squire & Dede, 2015; Squire & Zola-Morgan, 1991; Ullman, 2004; 2015; 2016). Second, learning in declarative memory has been shown to be aided by effortful attention (Foerde, Knowlton, & Poldrack, 2006). Third, the development of knowledge in declarative memory can occur rapidly, often after a single trial of learning (Eichenbaum & Cohen, 2001; Squire & Dede, 2015; Squire & Zola-Morgan, 1991; Ullman, 2004; 2015; 2016). Additionally, knowledge in declarative memory may be used flexibly with other knowledge in declarative memory as well as with knowledge from other memory systems. Thus, application of knowledge in declarative memory is not limited to the original context of learning, e.g., learning that the Cubs won the World Series in 2016 may be used in a discussion of other unusual events that happened in Chicago during that same year (Squire & Dede, 2015; Squire & Zola, 1996; Ullman, 2004; 2016).

Developmentally, learning abilities in declarative memory (a) mature later than procedural memory learning abilities, (b) improve until early adulthood, (c) remain relatively stable during middle adulthood, and then (d) decline in older adulthood (DiGiulio, Seidenberg, Oleary, & Raz, 1994; Lum, Kidd, Davis, & Conti-Ramsden, 2010; Rönnlund, Nyberg, Bäckman, & Nilsson, 2005; Ullman, 2015; 2016). Anatomically, learning in declarative memory is supported by the medial temporal lobe, which includes the hippocampal formation along with entorhinal, perirhinal, and parahippocampal cortex (Eichenbaum, 2011; Eichenbaum & Cohen, 2001; Squire & Dede, 2015; Squire & Zola-Morgan, 1991; Ullman, 2004; 2015; 2016). Lastly, cognitive tasks that have been used to assess declarative memory and its role in L2 acquisition include the Modern Language Aptitude Test, Part V (Carroll & Sapon, 1959), the Continuous Visual Memory Task (Trahan & Larrabee, 1988), the LLAMA-B (Meara, 2005), and the visual-auditory learning subtest of the Woodcock-Johnson III Tests of Cognitive Ability (Woodcock, Mather, & McGrew, 2001).

Evidence for the existence of declarative memory as a distinct memory system has been found in work with animal models, amnesic patients, and healthy humans. In animal models such as rats, temporary lesions to the hippocampus prevent the learning of place associations in a maze, whereas rats with functioning hippocampi learn these place associations (Packard & McGaugh, 1996). These results provide evidence for a distinct role of declarative memory in learning arbitrary facts, such as the locations of certain places in a maze. Work with amnesic patients has shown that damage to the medial temporal lobe prevents memory of training materials and episodes, but patients acquire skills such as reading mirror-inverted text and classifying probabilistic stimuli at the same rate as healthy controls (Cohen & Squire, 1980; Knowlton, Mangels, & Squire, 1996). Patients with damage to the striatum - a neural structure that supports procedural memory - but intact hippocampi show the opposite pattern of results. That is, these patients show intact recall of training episodes and materials but impaired skill acquisition (Knowlton et al., 1996). These results provide evidence of a role for declarative memory in recalling facts and personal episodes. Furthermore, work with healthy participants has shown that declarative memory can be involved in probabilistic classification, a task often supported by procedural memory, when there is no distracting task to occupy working memory capacity, demonstrating that declarative memory is often supported by effortful encoding and retrieval in working memory but is also a flexible memory system that can support learning on a wide variety of stimuli (Foerde et al., 2006). Overall, behavioral and neuroscientific research suggests that declarative memory is a distinct memory system primarily responsible for the acquisition of facts and personal experiences, but also notably distinguished by its flexibility to acquire a wide range of information.

Procedural Memory

Procedural memory is a type of implicit memory system that supports the acquisition of cognitive and motor skills as well as habits (Ashby, Turner, & Horvitz, 2010; Eichenbaum, 2011; Eichenbaum & Cohen, 2001; Henke, 2010; Morgan-Short, 2013b; Squire & Dede, 2015; Tulving, 1985; Ullman, 2004; 2015; 2016). For example, some motor skills supported by procedural memory include learning to shoot a basketball or to drive a car, and some cognitive skills include learning a new math technique or how to solve a Rubik's cube. Procedural memory may be described by a number of (neuro)cognitive characteristics. By 'implicit' it is meant that learning in procedural memory does not involve conscious awareness (Tulving, 1985; Ullman, 2004; 2015; 2016). Relatedly, learning in procedural memory is not supported by attention, and indeed attention may interfere with learning in procedural memory (Foerde et al., 2006). The development of knowledge in procedural memory occurs gradually and improves over multiple learning trials (Ashby et al., 2010; Ullman, 2004; 2015; 2016). Additionally, knowledge in procedural memory is typically encapsulated, meaning that it is unavailable for use by other memory systems and typically inflexible with respect to the contexts in which it can be applied, e.g., learning how to read mirror-inverted text may not transfer well to learning how to produce mirror-inverted text (Squire & Zola, 1996; Ullman, 2004).

Developmentally, learning abilities in procedural memory (a) mature earlier than learning abilities in declarative memory, (b) tend to be stable during childhood and adulthood, and (c) may decline in older populations, although research on age-related declines in procedural memory has produced a mixed pattern of results (DiGiulio et al., 1994; Lum et al., 2010; Nilsson, 2003; Ullman, 2015; 2016). Anatomically, procedural memory is supported by a striatal-thalamic-frontal circuit, in which information is relayed from the cortex to the striatum (part of the basal ganglia), then to the thalamus, then back to frontal cortex (Ashby et al., 2010; Eichenbaum, 2011). This functional circuit may reflect the planning and execution of skills that have been learned in procedural memory (Ashby et al., 2010; Eichenbaum, 2011; Eichenbaum & Cohen, 2001; Ullman, 2004; 2015; 2016). Lastly, cognitive tasks that have been used to assess procedural memory and its role in L2 acquisition include the Serial Reaction Time task (Lum & Kidd, 2012), Alternating Serial Reaction Task (Howard & Howard, 1997), Weather Prediction Task (Foerde et al., 2006; Knowlton, Squire, & Gluck, 1994), and the Tower of London (Kaller, Unterrainer, & Stahl, 2012; Unterrainer, Rahm, Leonhart, Ruff, & Halsband, 2003).

Evidence for procedural memory has been found in work with animal models, neuropsychology, and in cognitive and neuroimaging research with healthy participants. Work with animal models (McDonald & White, 1993; Packard & McGaugh, 1996), patient H.M. (Scoville & Milner, 1957), and other amnesic patients (Cohen & Squire, 1980; Knowlton et al., 1996) is suggestive of a dissociation between memory of cognitive and motor skills such as mirror drawing and memory of facts or episodes (Eichenbaum & Cohen, 2001; Squire & Dede, 2015). From these studies, researchers have concluded that skill knowledge is supported by a different system from that which supports factual or episodic knowledge, with skill knowledge being supported by procedural memory and factual/episodic knowledge by declarative memory. In a neuroimaging study with healthy humans, Foerde et al. (2006) demonstrated that the role of procedural memory in a probabilistic classification task is modulated by the presence of a secondary task. In this study, subjects learned to classify probabilistic stimuli under either single- or dual-task conditions in an fMRI scanner. The dual-task condition involved a secondary task that was designed to occupy working memory and thus reduce the amount of attention that participants were able to give to the probabilistic stimuli. If procedural memory does not depend on attention, then it should be more involved in the dual-task condition compared to the single-task condition, which would allow for attentional mechanisms to focus on the probabilistic stimuli. The results of the study showed a double dissociation in brain regions involved for learning in the single- and dual-task conditions. The striatum (a neural structure known to support procedural memory) was associated with learning in the dual-task condition but not the single-task condition, whereas the medial temporal lobe (a structure involved in declarative memory) supported learning in the single- but not the dual-task condition. The study is informative in that it shows functional and anatomical dissociations between declarative and procedural memory, and provides further support for the independence of procedural memory and attention. Overall, the behavioral and neuroscientific research literature suggests that procedural memory is a distinct memory system that operates independently of attention and conscious awareness and is primarily responsible for the acquisition of skills and habits.

Theoretical Perspectives on Declarative and Procedural Memory in L2 acquisition

Given overviews of the declarative and procedural memory systems, we now outline the three theories that have discussed various roles for declarative and procedural memory and knowledge in L2 acquisition. These theories include DeKeyser's Skill Acquisition Theory (DeKeyser, 2015), Paradis' declarative/procedural model (Paradis, 2009), and Ullman's declarative/procedural model (Ullman, 2004; 2015; 2016). Declarative and procedural memory (in DeKeyser, 'knowledge') play crucial roles in all of the theories discussed here, and yet less is known about the role of these long-term memory systems in L2 than is known about other relevant domain-general cognitive components, such as working memory. For each theory below, an overview of the theory along with its definitions of declarative and procedural memory or knowledge are provided, followed by a more detailed description of the theory and discussion of the specific roles that declarative and procedural memory play in the theory.

The first relevant theory, DeKeyser's Skill Acquisition Theory (DeKeyser, 2015), motivates second language learning as an instance of skill acquisition, with similarities between second language learning and other instances of skill acquisition, such as learning to play a sport or to play the piano. DeKeyser's conception of skill acquisition is consistent with that of other prominent theoretical perspectives on skill acquisition such as the Adaptive Character of Thought model (ACT-R, Anderson, 1996). Whereas DeKeyser (2015) does not speak of the role of declarative or procedural 'memory' systems in skill acquisition, he does discuss declarative and procedural ‘knowledge.’ Declarative knowledge is similar to declarative memory in the sense that it is characterized as knowledge ‘that’ and may be acquired quickly and via observation, i.e., without performance. For example, a learner can acquire declarative knowledge about a skill by watching others perform it, receiving verbal instructions, or undergoing some combination of these two processes. Likewise, procedural knowledge is similar to procedural memory in the sense that both involve the performance of complex skills and both tend to be informationally encapsulated. Procedural knowledge allows the learner to ‘chunk’ steps from declarative knowledge into a single routine. Note, however, that although declarative and procedural ‘memory’ and declarative and procedural ‘knowledge’ are similar, according to DeKeyser, ‘knowledge’ is the result of learning (cf. Anderson, 1996 where knowledge is the result of encoding information from the environment) and, thus, is not fully synonymous with ‘memory’ (DeKeyser, personal communication through review of chapter, December 30, 2017). This is in contrast to the perspective of the declarative and procedural memory system view where these memory systems are involved in both the learning and use of knowledge (Ullman, 2016). The tenets of Skill Acquisition Theory claim that skill learning progresses through the following three stages: the declarative stage, defined by the use of declarative knowledge; the procedural stage, defined by the use of procedural knowledge; and the automatic stage, in which the learner obtains automaticity by practicing the skill to reach a high level of competency where the knowledge becomes fine-tuned so that performance is faster, fewer errors are committed, and less attention is required to perform the task (DeKeyser, 2015). Declarative and procedural knowledge, then, are involved in two initial stages of skill acquisition during which knowledge is acquired about the skill and this knowledge is compiled into a routine for performance, respectively.

Importantly, in DeKeyser's model declarative knowledge does not interface with procedural knowledge in the sense that the output of declarative knowledge becomes the input of procedural knowledge, but rather DeKeyser simply claims that declarative knowledge plays a causal role in the development of procedural knowledge (DeKeyser, 2015, p. 103). This is in much the same way that one needs certain documentation, e.g., proof of residency, birth certificate, in order to obtain a state or national ID. However, it would be silly to argue that proof of residency becomes your state identification; it is simply a necessary condition for obtaining the identification. The same relationship obtains between declarative and procedural knowledge. Additionally, in a large number of studies skill acquisition has been shown to follow the power law of learning, a mathematical formalization of how competency increases with practice. DeKeyser emphasizes, however, that this continuous mathematical function is actually represented as a series of the three qualitatively distinct stages described above. In sum, then, DeKeyser's model may be understood to view L2 acquisition as an instance of skill acquisition, in which knowledge proceeds from a declarative to a procedural to an automatic stage. The concepts and predictions in the theory are all derived from this fundamental connection between language and skill acquisition.

A second model of L2 acquisition posits that declarative and procedural memory play crucial roles in learning a second language (Paradis, 2009). Paradis' definitions of declarative and procedural memory are largely consistent with how the terms were defined above in the 'Declarative Memory' and 'Procedural Memory' sections. However, it is important to note that for Paradis declarative memory is synonymous with explicit, i.e., conscious, knowledge and procedural memory is always implicit, i.e., nonconscious, knowledge, although Paradis accepts other forms of nonconscious knowledge. Note that this one-to-one mapping of declarative memory with conscious knowledge is not accepted by all researchers (Henke, 2010; Ullman, 2015). For L1, Paradis claims that all non-grammatical aspects of language, i.e., vocabulary, as well as any grammatical aspects that are under explicit control should be supported by declarative memory, and that all grammatical aspects that are under implicit control, i.e., syntax, morphology, and phonology, should be supported by procedural memory (Paradis, 2009). Paradis further claims that procedural memory should support lexical knowledge, maintaining a crucial distinction between the lexicon and vocabulary (Paradis, 2009, pp. 14-15). The lexicon, on the one hand, refers to the grammatical properties of lexical items, such as their subcategorization frames, e.g., ‘take’ requires a direct object. Vocabulary, on the other hand, refers to form-meaning pairings, which should be learned not in procedural memory but in declarative memory. For adult-learned second languages, Paradis predicts that most aspects of language, including grammar, lexicon, and vocabulary, will be learned explicitly in declarative memory. In sum, for L1 Paradis predicts that declarative memory involves learning vocabulary and explicit processing of grammar, whereas procedural memory is responsible for the implicit generation of grammatical structures, which includes syntactic, morphological, phonological, and lexical structures. For L2, Paradis predicts that declarative memory will dominate learning of most aspects of the L2. Indeed, Paradis suggests that the use of procedural memory in adult-learned L2 is rare, although it may be able to be utilized if learning occurs under immersion conditions.

As in DeKeyser’s Skill Acquisition Theory, in Paradis’ model declarative and procedural memory do not directly interface with each other. The relative reliance on procedural and declarative memory by the learner may change over time, but on logical and empirical grounds Paradis (2009) argues against any sort of interface between these two memory systems. In L1 acquisition, Paradis cites similarities in the processing of motor and cognitive skills and the processing of syntax, as well as clinical dissociations in the ability to learn motor and cognitive skills but inability to learn new words. Accordingly, this suggests a dissociation between syntax and vocabulary, which map onto procedural and declarative memory, respectively. However, declarative and procedural memory do not always support learning different aspects of a language in L2 acquisition, where analogous knowledge could in theory be learned in either system. Indeed, fluency in Paradis' model may be attained either through learning explicit knowledge in declarative memory or through acquiring implicit competence in procedural memory, but the way that learning is represented across these two categories is different. Paradis claims that learning in declarative memory involves "speeded-up controlled use" of grammar, whereas learning in procedural memory involves implicit competence through the internalization of grammar (Paradis, 2009, pp. 7-8). He further notes that most L2 learners use declarative memory to acquire explicit knowledge about their L2, but that with practice a few L2 learners may internalize the grammar and process it in procedural memory. The notion of analogous knowledge but distinct representations across the two memory systems extends the mechanisms by which declarative and procedural memory can contribute to learning a second language and is similar to notions discussed in Ullman's declarative/procedural model (Ullman, 2015), which we turn to next.

Ullman's declarative/procedural model (Ullman, 2004; 2015; 2016) claims that the long-term declarative and procedural memory systems have been coopted for use in language learning. Ullman's definitions of declarative and procedural memory are consistent with those provided in the memory sections above. According to Ullman's model, declarative memory is predicted to be responsible for learning arbitrary pieces of information, such as the meanings of content words, their lexical subcategorization specifications, and their phonological forms, in both L1 and L2, as well as storage of irregular and possibly higher frequency grammatical forms, especially in L2 (Ullman, 2015). Procedural memory is predicted to be responsible for learning rule-governed sequences and probabilistic information in language, such as rules in the mental grammar, especially at later stages of both L1 and L2 acquisition (Ullman, 2016). Additionally, procedural memory may play a role in the acquisition of syntactic categories as well as in acquiring the phonotactics of a language. Due to the developmental trajectory of procedural memory (see above), procedural memory is expected to play a stronger role for language learning in childhood compared to adulthood. In both Paradis' and Ullman's model, then, declarative memory contributes to the acquisition of word meanings and phonological forms, whereas procedural memory contributes to the acquisition of grammatical components of a language. However, the two models differ in their predictions for learning lexical subcategorization properties of words; in Paradis (2009) this information is learned in procedural memory, but in Ullman (2015; 2016) knowledge of subcategorization properties is predicted to be learned in declarative memory.

As in Paradis' and DeKeyser's models, Ullman's model posits that declarative and procedural systems do not interface with one another in the sense of sharing information. However, Ullman discusses two hypotheses concerning the relationship between declarative and procedural memory (Ullman, 2015, p. 139). The first is the redundancy hypothesis, which states that the two memory systems often acquire the same or analogous knowledge, and the second is the competition hypothesis, which claims that the two systems interact competitively such that acquiring knowledge in one system may inhibit learning in the other system. While it is clear that the two hypotheses make opposing predictions, it must also be considered that there are additional variables such as age of acquisition and the learning context that can affect whether declarative and/or procedural memory primarily underlies acquisition. For example, research has shown that the degree to which learners rely on declarative and procedural memory to process grammatical forms varies depending on the learning context, with implicit and immersion learners showing stronger evidence of reliance on procedural memory at later stages of acquisition (Brill-Schuetz & Morgan-Short, 2014; Faretta-Stutenberg & Morgan-Short, 2017). It should also be noted that the co-presence of knowledge across the two memory systems is not always bidirectional. This is because declarative memory is a much more flexible learning system compared to procedural memory, and thus it is often the case that knowledge learned in procedural memory can also be learned in declarative memory, but the reverse is not always true (Ullman, 2015; 2016). Some of the primary concerns in Ullman's model, then, are not simply what kinds of knowledge can be acquired in which system (declarative or procedural memory), but also how analogous knowledge is maintained across systems as well as how ancillary variables affect learning in both systems.

It should be clear from the preceding discussion that DeKeyser's, Paradis', and Ullman's models of L2 acquisition all predict roles for declarative and procedural memory and knowledge. In DeKeyser's Skill Acquisition Theory (DeKeyser, 2015), declarative knowledge is used at the beginning of learning to learn about aspects of a second language, and procedural knowledge is expected to develop at an intermediate stage of learning in which learners are practicing a second language but have not yet reached the stage where processing is automatic. In Paradis' model (Paradis, 2009), declarative memory is predicted to be responsible for most aspects of L2 acquisition, but in rare cases L2 learners may internalize grammatical and/or lexical aspects of L2 and process them in procedural memory. Ullman's model (Ullman, 2004; 2015; 2016) also predicts different roles for declarative and procedural memory in L2 acquisition, and additionally outlines hypotheses for the relationship between declarative and procedural memory, i.e., redundancy and competition hypotheses, and predicts important contributions from variables such as age of acquisition and the context of learning on the reliance of declarative and/or procedural memory in L2 acquisition. Relatedly, DeKeyser's theory and empirical work is also suggestive of interactions between age of acquisition and verbal aptitude (DeKeyser, 2000; DeKeyser, 2012a; DeKeyser, 2012b; DeKeyser, Alfi-Shabtay, & Ravid, 2010), which would presumably be related to declarative memory, as well as interactions between context of learning and the engagement of declarative and procedural knowledge, i.e., in study abroad versus classroom contexts (DeKeyser, 2007; DeKeyser, 2010). Although there are some important differences among the models, what all of the models have in common is a view of (a) declarative memory as involved in vocabulary and the initial stages of grammar learning, and (b) a stronger role for procedural memory for grammar at later stages of L2 acquisition. Below, an overview of empirical evidence for the role of declarative and procedural memory in L2 acquisition is presented with the intention to examine support for the general claims made across the models discussed here.

Evidence for the role of Declarative and Procedural Memory in L2 Acquisition

From the theories discussed above, it is clear that declarative and procedural memory are expected to play a role in L2 acquisition, but what evidence exists to demonstrate that this is indeed the case? This section reviews evidence on the role of declarative and procedural memory in L2 acquisition, focusing first on evidence from laboratory studies with one training condition and then on those with multiple training conditions, and finally, naturalistic learning studies (see Table 1 for summary). We include only studies that directly address predictions generated by declarative/procedural theories of L2 acquisition, but we also note that at least two studies have indirectly provided evidence for these theories by using tasks that we associate with procedural memory, although no claims were made about procedural memory in these two studies (Granena, 2013; Linck et al., 2013). Both of these studies demonstrate that tasks that involve sequence learning (which we believe reflects learning in procedural memory) predict language learning abilities.

Laboratory Studies with a Single Learning Condition

In this first subsection, we will consider laboratory studies that have examined L2 acquisition under a single context of learning. Looking at L2 acquisition under implicit training conditions, Morgan-Short, Faretta-Stutenberg, Brill-Schuetz, Carpenter, and Wong (2014) examined the role of individual differences in declarative memory, as measured by the Modern Language Aptitude Test, Part V (MLAT-V) and the Continuous Visual Memory Task, and procedural memory, as measured by the Tower of London and Weather Prediction tasks. In order to assess L2 learning ability, the authors used an artificial language paradigm, Brocanto2 (Morgan-Short, Finger, Grey, & Ullman, 2012; Morgan-Short, Sanz, Steinhauer, & Ullman, 2010; Morgan-Short, Steinhauer, Sanz, & Ullman, 2012), which they had adapted from Brocanto (Friederici, Steinhauer, & Pfeifer, 2002), in order to measure syntactic development under implicit training conditions. The findings from this study indicated that declarative memory ability predicted L2 syntactic development at early stages of acquisition, and that procedural memory ability predicted L2 syntactic development at later stages of acquisition. In a subsequent analysis of neuroimaging (fMRI) data that had been collected along with the Morgan-Short et al. (2014) study, Morgan-Short et al. (2015) examined the neural circuits associated with L2 acquisition under implicit contexts of exposure. Findings provided evidence of a link between learners who were strong in declarative memory and the use of procedural memory neural circuits in L2 processing at early stages of development. At later stages of development, learners who were low in procedural memory showed neural signatures indicative of effortful and attentional processing, but not neural signatures that indicate processing in procedural memory. The authors suggest that learners who are strong in declarative memory are able to quickly engage in a procedural stage of L2 syntactic processing, which provides evidence not only for a link between procedural memory and learning syntactic rules but also for perhaps a complementary relationship between declarative and procedural memory, as predicted by DeKeyser (2015) where strength in declarative memory may lead to rapid acquisition of declarative knowledge that then indirectly facilitates proceduralization.

Using a different artificial language paradigm that involved learning morphophonological rules in a passive, exposure-based condition, Ettlinger, Bradlow, and Wong (2014) examined the relationships between declarative memory, as measured by the visual-auditory learning subtest of the Woodcock-Johnson III test, and procedural memory, as measured by the Tower of London, and L2 acquisition. In this study, the simple rule involved straightforward application of a pattern of morphemes, whereas the complex rule involved vowel changes that could be learned via analogy with words presented in a training phase.[1] As such, learning the pattern rule was predicted to be supported by procedural memory due to the reliance on sequence learning, whereas learning the analogistic rule was predicted to be supported by declarative memory due to the need to recall analogous words to correctly apply this rule. The authors measured learning of the morphophonological rules in a forced-choice test, and analyzed the relationship between L2 learning and memory separately in three subgroups: (a) ‘learners,’ i.e., those participants who learned both the pattern and analogistic rules, (b) ‘simplifiers,’ i.e., those participants who incorrectly applied the pattern rule for analogistic cases, and (c) ‘nonlearners,’ i.e., those participants who did not show learning of either pattern or analogistic rules. Findings from this study indicated that participants who learned both the pattern and analogistic rules had high declarative and procedural memory, simplifiers had high procedural memory but low declarative memory, and nonlearners had low declarative and procedural memory. These results suggest that declarative memory is associated with learning the analogistic rule, and procedural memory is associated with learning the pattern rule and has a second-order association with the analogistic rule, such that participants with high procedural memory either scored well below chance on the analogistic rule (simplifiers) or above chance (learners).

Whereas Morgan-Short et al. (2014; 2015) and Ettlinger et al. (2014) looked at the role of declarative and procedural memory in implicit but intentional learning conditions, Hamrick (2015) used an incidental learning condition to examine the role of declarative memory, as measured by the LLAMA-B, and procedural memory, as measured by the Serial Reaction Time task, in L2 acquisition. Participants were exposed to new syntactic structures in a semi-artificial language (Hamrick, 2013) and then given a surprise recognition test that assessed their knowledge of the syntactic rules. The recognition test was given immediately after exposure to the language and after a 1-3 week period of no exposure. Findings from this study indicated that immediately after exposure to the semi-artificial language, declarative but not procedural memory abilities were correlated with performance on the surprise test, but after a 1-3 week period of no exposure, procedural but not declarative memory abilities were correlated with performance on the test.

Overall, these single learning condition, laboratory studies (Ettlinger et al., 2014; Hamrick, 2015; Morgan-Short et al., 2014) provide evidence for a role of declarative and procedural memory in learning syntactic and morphophonological rules under implicit and incidental contexts of exposure.

Laboratory Studies with Multiple Learning Conditions

Next, we move into laboratory studies that look at multiple contexts of learning. The first study that we review, Antoniou, Ettlinger, and Wong (2016), extended Ettlinger et al.'s (2014) research with morphophonological L2 learning under a passive, exposure-based condition and examined whether the role of declarative and procedural memory changes in conditions in which feedback during testing and the order of presentation of the pattern and analogistic L2 rules are manipulated. Declarative memory was measured by the visual-auditory learning subtest of the Woodcock-Johnson III test, and procedural memory was measured by the Tower of London, following Ettlinger et al. (2014). Findings from this study replicated those of Ettlinger et al. (2014) in that declarative memory was associated with learning the analogistic rule and that procedural memory was associated with learning the pattern rule in all conditions, except for when the analogistic rule was presented before the pattern rule. For this ordering of the rules, declarative memory was associated with learning the pattern rule, suggesting that the role of declarative and procedural memory may be mediated by the structure of the input itself.

A few studies have extended previous research with implicit, exposure-based, and incidental conditions to examine whether procedural memory makes different contributions in explicit, instructed conditions. First, examining the effects of implicit vs. explicit training conditions, Brill-Schuetz and Morgan-Short (2014) considered the role of procedural memory, as measured by the Alternating Serial Reaction Task and the Weather Prediction Task, in learning syntactic, word order rules of an artificial language. Their results showed that procedural memory ability interacted with training condition such that participants with high procedural memory were more accurate on a grammaticality judgment task than were participants with low procedural memory, but only in the implicit training condition. A second study examined the role of procedural memory in incidental and instructed conditions using a semi-artificial language with simple and complex word order rules (Tagarelli, Ruiz, Vega, & Rebuschat, 2016). Procedural memory, as measured by the either the Serial Reaction Time task or the Alternating Serial Reaction Task,[2] was found to be negatively associated with L2 acquisition of syntax, particularly for one complex word order rule, in the incidental but not the instructed learning condition. The authors noted that the use of a semi-artificial language and an untimed grammaticality judgment test to assess L2 knowledge may have biased learners in the incidental condition towards explicit processing, and thus less reliance on procedural memory. Overall, both Brill-Schuetz and Morgan-Short (2014) and Tagarelli et al. (2016) found evidence for both facilitative and interfering roles for procedural memory in implicit and incidental conditions, which is largely consistent with the single context, laboratory studies reviewed above. However, no role for procedural memory was evidenced in explicit and instructed conditions.

A final, laboratory study, Suzuki (2017), specifically examined the role of procedural memory in explicit training conditions that differed by inter-session spacing intervals with 3.3-day or 7-day intervals between sessions. Suzuki measured the automatization of L2 morphology of a miniature language with reaction times and a coefficient of variance (CV),[3] and assessed procedural memory with the Tower of London task. Results indicated that procedural memory was associated with the speedup of L2 processing, as measured by reaction time, but only in the group given short (3.3-day) intervals of learning. Procedural memory, however, was not associated with more stable processing, as measured by the coefficient of variance, and as such was argued to play a role only in earlier stages of automatization. The results of this study suggest that procedural memory may also play a role in explicit and instructed conditions when reaction time is considered as opposed to accuracy, which was the L2 measure examined in previous studies that included an explicit or instructed condition (Brill-Schuetz & Morgan-Short, 2014; Tagarelli et al., 2016).

Naturalistic Learning Studies with Multiple Learning Conditions

To our knowledge, only one study has examined the role of declarative and procedural memory in a naturalistic learning context. Faretta-Stutenberg and Morgan-Short (2017) examined the role of declarative memory, as measured by the MLAT-V and Continuous Visual Memory Task, and procedural memory, as measured by the Alternating Serial Reaction Task and Weather Prediction Task, in L2 acquisition of Spanish syntax in a longitudinal study of two naturalistic contexts: study-abroad and at-home, university-level L2 learners of Spanish. They assessed both behavioral changes (via a grammaticality judgment task) and neurocognitive processing changes (via event-related potentials). Results from this study did not provide evidence of a link between declarative memory and L2 learning in either context despite L2 improvements for learners in both contexts, but declarative memory was positively correlated with baseline L2 performance, suggesting that declarative memory is important at early stages of learning. Procedural memory was related to changes in both behavioral performance (improved performance) and neurocognitive processing (N400 and P600 effects) in the second language, but this relationship only held in the study-abroad context of learning. The authors posit that this connection between procedural memory and the study-abroad context may be due to the less instructed and more abundant second language input in study-abroad contexts compared to at-home contexts.

Taken together, laboratory and naturalistic, multiple learning condition studies (Antoniou et al., 2016; Brill-Schuetz & Morgan-Short, 2014; Faretta-Stutenberg & Morgan-Short, 2017; Suzuki, 2017; Tagarelli et al., 2016) of L2 acquisition provide additional evidence for a role for declarative and procedural memory in learning syntactic, morphological, and morphophonological grammatical rules. The results from these studies also suggest that the contributions that these memory systems make may differ by context.

[INSERT TABLE 1 HERE]

Summary of Evidence

Overall, the studies reviewed above implicate roles for declarative and procedural memory in L2 acquisition and begin to shed light on what these roles are (see Table 1 for summary). Regarding declarative memory, these studies broadly implicate a positive role for declarative memory (a) at earlier stages of L2 learning (Faretta-Stutenberg & Morgan-Short, 2017; Hamrick, 2015; Morgan-Short et al., 2014); (b) in implicit, exposure-based, incidental and classroom contexts (Antoniou et al., 2016; Faretta-Stutenberg & Morgan-Short, 2017; Hamrick, 2015; Morgan-Short et al., 2014); (c) in learning analogistic rules when L2 input is not ordered (Antoniou et al., 2016; Ettlinger et al., 2014); and (d) in learning pattern rules when preceded in the input by analogistic rules (Antoniou et al., 2016). Regarding procedural memory, these studies suggest that procedural memory is positively associated with L2 learning (a) at later stages of learning (Brill-Schuetz & Morgan-Short, 2014; Faretta-Stutenberg & Morgan-Short, 2017; Hamrick, 2015; Morgan-Short et al., 2014); (b) in implicit, exposure-based, incidental, and immersion contexts, but not in classroom contexts or in explicit contexts (Antoniou et al., 2016; Brill-Schuetz & Morgan-Short, 2014; Ettlinger et al., 2014; Faretta-Stutenberg & Morgan-Short, 2017; Hamrick, 2015; Morgan-Short et al., 2014); (c) in explicit contexts for reaction time measures (Suzuki, 2017); and (d) in learning pattern rules (Antoniou et al., 2016; Ettlinger et al., 2014).

It is important to note that not all of the findings related to the role of declarative and procedural memory are positive or consistent. For example, recall that Tagarelli et al. (2016) evidenced a negative relationship between procedural memory and syntactic development in an incidental condition. Also, in-progress work in our laboratory that aims to replicate and extend Ettlinger et al. (2014) is finding a positive relationship between pattern rules with declarative memory as well as with procedural memory, as measured by the Weather Prediction Task but not as measured by the Tower of London task (Buffington & Morgan-Short, in progress). Note, however, that this pattern of results differs from those of Ettlinger et al. (2014) and Antoniou et al. (2016) in that they found a positive relationship between analogistic learning and declarative learning and with pattern learning and procedural memory, as measured by the Tower of London task. These examples demonstrate that much more replication and extension work will need to be conducted in order to fully understand the roles of declarative and procedural memory in L2 learning. Overall though, the evidence reviewed above largely converges on the general finding that declarative and procedural memory seem to be related to the ability to learn grammatical structures in a second language, but that this role is somewhat contingent on the stage of the learning process, the context of learning, the type of grammatical rule, and potentially even the cognitive task used to assess procedural memory.

Conclusions and Future Directions

This chapter has reviewed theories and evidence on the role of declarative and procedural memory as individual differences in predicting outcomes in L2 acquisition. We offered detailed definitions of declarative and procedural memory and described three theories that predict roles for declarative and procedural memory in L2 acquisition (DeKeyser, 2015; Paradis, 2009; Ullman, 2015). These models all share an expectation that declarative memory will support learning of grammatical structures in L2 at early phases of learning, whereas procedural memory will play an increasingly important role for these structures as L2 proficiency develops. Empirical evidence largely provides support for the claims generated by these models. However, we note that the scope of previous research is limited to syntactic, morphological, and morphophonological grammatical structures, and most studies to date have examined learning in a laboratory-based, implicit or exposure-based context. As such, future research would benefit from studying a wider range of linguistic structures, e.g., phonological and lexico-semantic structures, and more systematically studying L2 acquisition in explicit instruction contexts, particularly to examine understudied aptitude/treatment interactions such as the role of declarative memory in explicit environments.

In addition to further exploring when these long-term memory systems play a role in L2 learning, e.g., at what stage, under what contexts, and for which linguistic structures, future research should also address what we believe to be important, but underexplored, questions generated by the declarative/procedural theory of L2 acquisition. For one, most empirical work to date is largely consistent with all three declarative/procedural models, but the models also make differing predictions, e.g., regarding the role of declarative memory in learning explicit vs. implicit information. Second, Ullman (2015; 2016) notes that declarative and procedural memory can interact cooperatively and competitively with each other. While Morgan-Short et al. (2015) provide evidence that suggests that learners high in declarative memory quickly switch to procedural memory neural circuits during L2 acquisition, the cooperation and competition hypotheses should continue to be investigated in future research. For one, it is not known when declarative and procedural memory interact cooperatively in L2 acquisition and when they interact competitively, as well as what mechanisms mediate these relationships. Third, it is important to consider the relative contributions of declarative and procedural to memory to L2 acquisition in light of the contributions of other domain-general constructs such as working memory (Wen, this volume) as well as any domain-specific constructs that contribute to L2 acquisition (Sparks, Patton, & Luebbers, this volume; Yue, this volume). Lastly, an important body of work has examined the contributions of implicit learning (e.g., Granena, 2013; Granena & Yilmaz, this volume; Linck et al., 2013) and statistical learning (e.g., Frost, Siegelman, Narkiss, & Afek, 2013) to L2 acquisition. It is not clear to us how these constructs do or do not map onto declarative and/or procedural memory, and we are not aware of any work attempting to relate these constructs to one another (see Granena & Yilmaz, this volume, for related discussion). Given that implicit learning, statistical learning, declarative memory, and procedural memory are all claimed to be broad, domain-general constructs, and are often assessed with the same cognitive task, e.g., the serial reaction time task, there is likely a substantial amount of overlap among the constructs. This may be especially true for implicit learning and procedural memory, since both systems are understood to be implicit memory systems. However, comparing the contributions of these systems may reveal some intriguing differences. Clearly delineating the relationships among these constructs will add to our understanding of the neurocognitive mechanisms underlying L2 acquisition and undoubtedly generate important questions for future research.

While research on the contributions of declarative and procedural memory to L2 acquisition is just beginning to emerge, the early findings show that declarative/procedural theory of L2 acquisition can explain a number of L2 acquisition phenomena, and work in this area is inviting and leading to research on important theoretical questions regarding the component mechanisms underlying the ability to learn languages. Finally, to the extent that L2 aptitude is comprised of cognitive abilities that together could serve as a “composite measure regarded as the general capacity to master a foreign language” (Wen et al., 2017), we posit that declarative and procedural memory, as domain-general, cognitive, long-term memory constructs should potentially be considered a part of L2 aptitude.

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Endnotes

[1] Ettlinger et al. (2014) use ‘simple’ and ‘complex’ rules to refer to the simple, pattern rule and the complex, analogistic rule, respectively. Because of the opacity of the terms ‘simple’ and ‘complex,’ we will refer to the two types of rules as ‘pattern’ and ‘analogistic,’ respectively, as we believe these terms are more descriptive and clear.

[2] Participants completed either the Serial Reaction Time task or the Alternating Serial Reaction Task. It seems that the reason for including two different tasks was that the Alternating Serial Reaction Task could not be run in the U.K. for technical reasons, and so the Serial Reaction Time task was used as a substitute (around half of participants were run in the U.K. and half in the U.S.).

[3] Coefficient of variance is the standard deviation divided by the mean ($s/\bar{x}$). In this study, coefficient of variance was indexed by dividing the standard deviation of reaction time by the mean reaction time. The authors refer the reader to Segalowitz and Segalowitz (1993) for the rationale of using the coefficient of variance to index automatization.

Table 1

Studies Examining the Relationship between L2 Acquisition and Declarative and Procedural Memory

Reference	Context of learning	L2	Declarative memory (DM) and L2	Procedural memory (PM) and L2
Ettlinger et al., 2014	Passive, exposure-based	Artificial language: Morphophonology based on Shimakonde	DM associated with learning analogistic grammatical rule	PM linearly associated with learning pattern grammatical rule; second-order association with learning analogistic grammatical rule
Antoniou et al., 2016	Passive, exposure-based with or without feedback and presentation order	Morphophonology based on Shimakonde	DM predicted learning of analogistic rule; DM predicted pattern rule learning when analogistic rule presented before pattern rule	PM predicted learning of pattern rule
Buffington & Morgan-Short, in progress	Passive and exposure-based	Morphophonology based on Shimakonde	DM correlated with learning of pattern rule	Only one PM task (Weather Prediction Task) correlated with learning of pattern rule
Suzuki, 2017	Explicit	Artificial language: morphology based on Spanish	NA	PM associated with speedup, and early automatization, in short-interval learning group
Morgan-Short et al., 2014	Implicit	Artificial language: Brocanto2	DM predicted L2 ability at early stage of learning	PM predicted L2 ability at later stage of learning
Morgan-Short et al., 2015	Implicit	Brocanto2	No direct relationship between DM and L2, but DM ability associated with PM neural circuits at early stage	Low PM ability associated with effortful processing at later stage
Brill-Schuetz &	Implicit and explicit	Artificial language: Brocanto2	NA	PM associated with L2 ability in implicit condition

Morgan-Short, 2014				
Hamrick, 2015	Incidental	Semi-artificial language: English vocabulary and Persian-based syntax	DM correlated with L2 ability at early stage of learning	PM correlated with L2 ability at later stage of learning
Tagarelli et al., 2016	Instructed and incidental	Semi-artificial language: English vocabulary and German syntax	NA	PM negatively associated with L2 acquisition in incidental group
Faretta-Stutenberg & Morgan-Short, 2017	Study-abroad and at-home /classroom	Spanish syntax	No predictive role for DM in L2 learning, but DM correlated with L2 ability at baseline testing	PM predicted L2 learning in study-abroad group