

# *State of the Scholarship*

## IMPLICIT LANGUAGE APTITUDE: CONCEPTUALIZING THE CONSTRUCT, VALIDATING THE MEASURES, AND EXAMINING THE EVIDENCE

INTRODUCTION TO THE SPECIAL ISSUE

**Shaofeng Li** \*

*Florida State University*

**Robert DeKeyser**

*University of Maryland*

### **Abstract**

This article discusses the conceptualization, measurement, and validity of a recently emerged construct in the field of second language acquisition (SLA)—implicit language aptitude (alternatively “implicit aptitude”). Implicit aptitude is a set of cognitive abilities that enable learners to make unconscious computations of the distributional and transitional probabilities of linguistic input. Implicit aptitude is key to an accurate understanding of the cognitive foundation of language learning and contributes significantly to the advancement of SLA theory and pedagogy. The article starts by clarifying the concept and components of implicit aptitude, elaborating its role in SLA theories, identifying its attributes, and discussing its measurement. It then synthesizes the empirical evidence on its divergent, convergent, and predictive validity, which refers to whether it is distinct or separable from explicit aptitude, whether measures of implicit aptitude are correlated, and whether it is predictive of learning outcomes, respectively. Next, the article provides an overview of the seven empirical studies included in this special issue that examined implicit aptitude from various perspectives. The article concludes by identifying future directions.

### **INTRODUCTION**

The purpose of this thematic issue of *Studies in Second Language Acquisition* is to examine the validity of a recently emerged construct that is essential to an accurate understanding of the mechanism of second language acquisition (SLA)—aptitude for

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\* Correspondence concerning this article should be addressed to Shaofeng Li, School of Teacher Education, Florida State University, 1114 West Call Street, Tallahassee, Florida 32306. E-mail: [sli9@fsu.edu](mailto:sli9@fsu.edu)

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implicit language learning (alternatively referred to as “implicit language aptitude” or “implicit aptitude”). In this article, we define implicit language aptitude as a cluster of cognitive abilities that (a) enable learners to conduct unconscious computation of the distributional and transitional probabilities of linguistic input, and (b) are predictive of learning rate and ultimate attainment. In this conceptualization, implicit aptitude has the following attributes. First, it is componential, that is, it is not a unitary construct; rather, it is a cognitive device consisting of multiple abilities responsible for different aspects of second language (L2) development. Second, it is distinct from cognitive abilities in the explicit domain such as working memory and traditional language aptitude—the type measured by the Modern Language Aptitude Test (MLAT) (Carroll & Sapon, 2002). Third, it is a trait variable<sup>1</sup> that causes individual variation among learners and leads to differences in learning outcomes. Therefore, it is a predictor of attainment, not attainment per se, unlike the way it is typically conceptualized in psychological research. Fourth, it is predictive of learning rate as well as the end state of a second language, unlike explicit aptitude which is purported to only predict learning rate (Carroll, 1981). Fifth, it consists of both domain-general cognitive abilities that underlie all kinds of learning as well as domain-specific abilities that are exclusively important for language learning. These claims form the core of the concept of implicit aptitude. We hope to contribute to the theorization of this construct through the special issue and examine its validity through the included studies.

The notion of implicit learning is not new, but the notion of implicit learning ability as a predictor of learning outcomes is. In psychology where the study of implicit learning through psychometric tasks made its debut, the research has centered on whether and how implicit learning occurs, not whether learners differ in their ability for implicit learning. One defining characteristic of implicit learning, according to mainstream psychological theories and research, is its homogeneity and lack of individual variation (Reber, 1993; Stanovich, 2009). Individual differences, when observed, are often treated as “noise”—“error or otherwise unexplained variance” (Kaufman et al., 2010, p. 322). Thus, there has been little interest in investigating factors responsible for individual variation, and implicit learning ability as a predictor of learning outcomes is largely ignored. However, although in general there is less variance in implicit learning than explicit learning, there is empirical evidence for systematic variability in implicit learning (Kaufman et al., 2010; Misyak & Christiansen, 2012). There is also evidence that the low variability in implicit learning is partly due to the low reliability of the measures or tasks utilized to detect implicit learning; the low reliability is likely due to the lack of constraints in implicit learning tasks, which makes learners’ responses to task stimuli inconsistent (Ward et al., 2013).

In SLA, the debate over implicit and explicit learning is at the core of theory, research, and pedagogy. This thematic issue does not intend to resolve the controversy over the two types of learning. Rather, it seeks to foreground one perspective—the underlying abilities for implicit and explicit learning—that will enhance our understanding of the intricacy pertaining to how implicit and explicit learning are distinct and related and in what way they jointly and independently contribute to L2 attainment. In SLA, the research on implicit aptitude commenced with attempts to identify cognitive abilities for high-level proficiency (Linck, 2013), map the relationship between different aptitudes and maturation effects (Granena, 2013; Long & Granena, 2013), and identify the nature of L2 knowledge by exploring its associations with cognitive aptitudes (Suzuki & DeKeyser, 2015, 2017). It is also motivated by the fact that after more than six decades of aptitude

research, traditional aptitude has been found to be a set of abilities that are more strongly (if not only) correlated with the effects of explicit instruction than those of implicit instruction (Li, 2015, 2016, 2017a). Since its inception, there has been a steady growth of interest in various aspects of the construct of implicit aptitude. The scope of inquiry encompasses morphosyntax (Tagarelli et al., 2015) as well as pronunciation (Saito et al., 2019) and vocabulary (Yi, 2018). The research has examined not only its predictive power (Granena, 2019) but also its interface with treatment type (Granena & Yilmaz, 2019). The measurement of implicit aptitude spans both psychometric tests such as serial reaction time (SRT) and electrophysiological methods (Saito et al., 2019). In the meantime, there has also been a growth of research in related paradigms such as declarative and procedural memory (Hamrick, 2015; Morgan-Short et al., 2014) and statistical learning (McDonough & Trofimovich, 2016).

However, the research on implicit aptitude is in its infancy and many issues remain. For example, there has been conceptual and methodological inconsistency in the research; there has been a lack of communication between the different paradigms in which it has been examined; there are many unexplored topics; and its significance has yet to be imparted to a wider audience in the field. Bringing together leading scholars in this domain, this thematic issue aims to show how implicit aptitude can be investigated from multiple perspectives, examine the validity of the measures of the construct, explore new variables, and identify new directions. We hope to place this topic center stage in SLA with a view to clarifying the construct, contributing methodological innovations, increasing methodological rigor, and enhancing our understanding of implicit aptitude and implicit learning—the “default” learning mechanism of SLA (Ellis & Wulff, 2015; Long, 2015). In the following sections, we discuss the theoretical and pedagogical significance of implicit aptitude, elaborate its nature and components, and summarize the findings of the research to date. We then provide an overview of the seven empirical studies included in this special issue examining implicit aptitude from various perspectives.

### **THE THEORETICAL AND PEDAGOGICAL SIGNIFICANCE OF IMPLICIT APTITUDE**

The importance of implicit aptitude rests on the assumption that implicit learning exists and that it is separable from explicit learning. According to dual-process theories of human learning, knowledge and skills are acquired in two distinct ways: through explicit learning characterized by effortful and deliberate processing of information and through implicit learning characterized by unconscious computation of the relationships between available materials in the environment. Explicit learning is more recent in human evolution; it is attention-driven, analytic-rational, efficient, short-lived, and transferable between different knowledge and skill domains. It is typically associated with attributes of “being smart” and is measured through traditional intelligence tests. Implicit learning is evolutionarily more primitive in that the initial state of human knowledge is primarily intuitive and tacit knowledge before it becomes conscious and rational. Implicit learning is data-driven, intuitive, slow, sustainable, and not easily transferable between domains. The large body of psychological research conducted in different paradigms, such as artificial grammar, SRT, statistical learning, declarative versus procedural memory, and priming, has provided robust evidence for the existence of implicit learning and its separation from explicit learning. One importance piece of evidence that has been used

to prove its existence is that cognitive abilities underlying conscious learning (typically measured using IQ tests) such as associative memory and reasoning are only correlated with the effects of explicit learning tasks but uncorrelated, or even negatively correlated, with the effects of implicit learning tasks (Gebauer & Mackintosh, 2007; Reber et al., 1991; Robinson, 2005). Evidently, mapping the relationship between implicit and explicit learning abilities and learning outcomes is fruitful in unraveling the relationship between implicit and explicit learning. However, to most psychological researchers, learners differ only in their explicit learning abilities such as IQ, and they do not vary in their ability for implicit learning. Accordingly, most research has investigated the process, outcome, and measurement of implicit learning, instead of conceptualizing it as a cognitive ability. However, there has been evidence that aptitude for implicit learning is “a reliable and stable capacity of the individual” (Siegelman & Frost, 2015, p. 18) because of its high test-retest reliability and its predictive power for outcome variables (Siegelman et al., 2017). Therefore, there is a need to add implicit aptitude in the theory and research on the implicit-explicit distinction.

In SLA, the focus of theory and research has been on the debate over whether second language learning is explicit or implicit (Krashen, 1981), the comparative effectiveness of explicit and implicit instruction (Kang et al., 2019; Norris & Ortega, 2000), and the measurement of explicit and implicit knowledge (R. Ellis, 2005). The explicit versus implicit distinction was not made in aptitude research until recently. The research on language aptitude has centered on explicit aptitude (phonetic coding, analytic ability, and rote memory), and there has been little theorization and research on implicit aptitude. Here, we would like to contextualize the discussion of implicit aptitude by examining its role in major SLA theories because the theoretical claims have important implications for how to conceptualize and operationalize this new construct. It is worth clarifying that these theories do not make explicit claims about the role of language aptitude, but their claims about how learning occurs are suggestive of the mediating role of implicit and explicit aptitude.

First, according to the usage-based approaches to SLA, “the bulk of language acquisition is implicit learning from usage” (N. Ellis, 2005, p. 306); language learning is input-based and relies primarily on the implicit tallying of available cues regarding the relationship between units of the linguistic materials learners encounter. The theory also holds that language learning is a matter of sequence learning: sequences of sounds, words, and phrases and the regularities underlying the sequences. The claims about how learning occurs based on usage-based approaches coincide with the mechanism of implicit aptitude, which has been operationalized as sequence learning, tested through SRT tasks where subjects learn the probabilistic relationships between stimuli through repeated exposure without awareness. Ellis further argues that explicit learning is also necessary, but its role is restricted to certain aspects of vocabulary and to focusing learners’ attention on nonsalient structures that may go unnoticed by learners. However, even in cases in which explicit learning happens, its purpose is to help learners establish initial representations of the constructions and prepare learners for implicit learning.

The usage-based approaches have a profound influence on the claims about the role of implicit learning in the Interaction Hypothesis, a currently popular SLA theory proposed by Long (1996, 2015). The core tenet of the Interaction Hypothesis is that the optimal condition for L2 learning is when learners’ attention is drawn to linguistic forms during

meaning-primary interaction. Attention to form needs to be brief, reactive, and ideally provided through implicit negative feedback such as recasts, which refer to the reformulation of an erroneous utterance without changing the meaning. In what way is this theory related to implicit aptitude? Similar to the usage-based approaches, the Interaction Hypothesis holds that implicit learning is the default learning mechanism of second language acquisition. However, according to Long (2015), the ability for implicit learning, which children have full access to, declines in adults. Therefore, implicit learning by adults needs to be aided by “intentional initial perceptions of new forms and form-meaning connections” (p. 49). Long further argued that the initial perception requires minimal attentional resources and does not require metalinguistic awareness of forms. The purpose of this level of attention is to “tune in to” selected input, and further processing of the input will be taken over by implicit learning after the initial representation. Long also cited evidence that implicit and explicit learning are conducive for the learning of different structures: while the former advantages adjacent items (e.g., AB) and complex structures, the latter favors structures involving long-distance dependencies (AXB) and simple structures. However, there is evidence that implicit learning is effective for both adjacent and nonadjacent structures (Misyak & Christiansen, 2012). Overall, it can be inferred that implicit aptitude plays a key role in the Interaction Hypothesis and that implicit aptitude is at its best when aided by low levels of attention—perception or detection, not understanding or metalinguistic awareness.

Skill Acquisition Theory (DeKeyser, 2020) posits three stages involved in language learning: declarative knowledge, proceduralization, and automatization. Declarative knowledge refers to knowledge about language such as grammar rules, word-meaning associations, and knowledge about sounds. Declarative knowledge is proceduralized when applied in actual linguistic behaviors and is automatized through repeated practice. DeKeyser indicated that the declarative-procedural distinction is largely equivalent to the explicit-implicit distinction, although they are not entirely identical. As to the role of language aptitude, DeKeyser stated that Skill Acquisition Theory attaches importance to language aptitude “because of its emphasis on the importance of explicit/declarative knowledge in initial stages of learning” (2020, p. 91). Clearly, language aptitude refers to traditional explicit aptitude in this claim. Given that proceduralization and automatization involve implicit learning, implicit aptitude is likely implicated at these two stages of learning, which are more advanced than declarative knowledge. A corollary is that explicit aptitude is involved more in initial learning and implicit aptitude more in advanced learning. DeKeyser pointed out that in addition to playing different roles at different learning stages, there are other ways implicit and explicit learning work in “synergy.” For example, implicit learning may lead to implicit knowledge, and explicitly learned knowledge may lead to automatized knowledge that is functionally equivalent to implicit knowledge. Based on this argument, it can be hypothesized that both implicit and explicit aptitude contribute to implicit knowledge in that the former plays a direct role in leading to implicit knowledge and the latter plays an indirect role by means of facilitating automatized L2 knowledge that may not be discernable from implicit knowledge. However, as DeKeyser pointed out, the primary concern of Skill Acquisition Theory is how declarative knowledge can be effectively learned and how it is proceduralized and automatized through practice, and whether the eventual knowledge is implicit or explicit is of less importance.

Another theory that makes similar but not identical claims as Skill Acquisition Theory is the Declarative/Procedural (D/P) Model. Similar to Skill Acquisition Theory, the D/P model makes a distinction between declarative and procedural systems, but instead of treating them as knowledge, in the D/P model they are referred to as two types of long-term memory where knowledge is learned and stored. In this model, declarative memory is responsible for the learning of “idiosyncratic (non-derivable) information and arbitrary associations” (Ullman & Lovelett, 2018, p. 41), including words (spelling, meaning, sound-meaning associations), idioms, and unanalyzed chunks (including irregular morphological forms such as irregular verb past forms). Procedural memory, which is “a type of implicit memory system” (Buffington & Morgan-Short, 2019, p. 217), is responsible for grammar learning or the learning of sequences, rules, and patterns. However, Ullman claims that grammar can also be learned in declarative memory, which is especially true of adults whose procedural memory is not as strong as their declarative memory. Declarative memory holds primarily explicit knowledge, but it also stores implicit knowledge; however, all explicit knowledge is learned in declarative memory. Procedural memory is the only storage space for implicit knowledge, although there are different mechanisms for learning implicit knowledge (such as priming, sequence learning, etc.). The learning that happens in declarative memory is fast and requires minimal exposure, while in procedural memory learning is slow and gradual and requires massive exposure. Whether learners deploy their procedural or declarative memory depends on external factors such as the learning setting, for example, explicit instruction will encourage learners to utilize their declarative memory and, in the absence of explicit instruction, learners will have to rely on their procedural memory. One important claim of the D/P model is that the activation of one memory system may inhibit or override the other. Based on the claims of the D/P model, we can roughly equate declarative memory with explicit aptitude and procedural memory with implicit aptitude, although the scope of aptitude is larger than memory. For example, declarative memory has been operationalized as rote (associative) memory and recognition memory, while in the paradigm of language aptitude explicit aptitude encompasses phonetic coding and analytic ability in addition to rote memory. In cognitive psychology, declarative and procedural memory are called explicit and implicit memory, respectively (Goldstein, 2011). Finally, the D/P model focuses more on the different functions and contents of the two types of long-term memory than on how declarative memory can be proceduralized through practice—a main concern of Skill Acquisition Theory.

To conclude the theoretical discussion of the role of implicit aptitude (and in relation to explicit aptitude),<sup>2</sup> we would like to summarize the main claims derived from the above-mentioned SLA theories. Although most of these claims are theoretical and have yet to be tested in aptitude research, they provide insights that may serve as hypotheses to be examined empirically.

- Implicit aptitude makes an independent contribution to SLA by means of unconsciously extrapolating the regularities governing the distribution and contingencies of linguistic input.
- Implicit aptitude contributes to the learning of structures involving adjacent items as well as structures involving long-distance dependencies.
- Implicit aptitude is more effective for complex structures while explicit aptitude may have larger effects for simple structures.
- Implicit aptitude is more efficient when learners process input initially established in their focal attention but the amount of attentional resources required for such initial representation is

- minimal—unlike the high levels of awareness and participatory demands required for explicit learning.
- Implicit aptitude is more likely to be implicated in advanced L2 learning while explicit aptitude is more important in initial learning.
  - Implicit aptitude may contribute directly to implicit knowledge while explicit aptitude may contribute to implicit knowledge indirectly by providing fodder (declarative knowledge) for implicit learning.
  - Implicit aptitude is slow and requires repeated exposure while explicit aptitude is quick and efficient.
  - Implicit aptitude is more likely to be resorted to when there is a lack of external force diverting learners' attention to linguistic forms while explicit aptitude is drawn on when learners are required or encouraged to consciously process linguistic materials.
  - Other things being equal, implicit aptitude is more likely to be implicated in grammar learning while explicit aptitude plays a greater role in lexical learning.
  - Implicit and explicit aptitude may interfere with each other in certain learning conditions.

Research on implicit aptitude may not only enhance our understanding of the theory and mechanisms of SLA but also provide valuable pedagogical implications. First, results of aptitude tests have been used to select candidates with the potential to master a foreign language within a short period (such as in state-funded language programs in the United States), place learners with comparable aptitude levels into different streams of classes, provide counseling to learners in terms of adopting strategies that fit their aptitude profiles, make decisions about waiving foreign language requirements, and evaluate the effectiveness of instruction (Li, 2017b, 2018, in press). However, current aptitude assessment is dominated by tests of explicit aptitude such as the MLAT (Carroll & Sapon, 2002) and other tests modeled on the MLAT such as the LLAMA (Meara, 2005). If implicit aptitude makes an independent contribution to L2 attainment, then the assessment of language aptitude should include measures of implicit aptitude, and an aptitude test without implicit aptitude is incomplete. Second, the notion of implicit aptitude fits the mechanism of the currently popular task-based instruction and other meaning-oriented approaches where language is taught through meaning-primary tasks (Ellis et al., 2020; Long, 2015). These approaches seek to foster learners' communicative competence, which draws primarily on implicit knowledge. It can be hypothesized that implicit aptitude will be more likely to be involved in meaning-oriented instruction and explicit aptitude is more strongly correlated with the effects of more form-oriented instruction. If the hypothesis is confirmed, the findings will provide evidence that (a) learning happens through two different processes under different learning conditions, (b) different instructional approaches work for learners with different aptitude profiles, and (c) learners who are classified as not having the intelligence or prowess for language learning based on traditional aptitude measures may be stronger in unconscious learning and therefore have better chances of success if they are taught in ways that unlock their strengths.

#### THE NATURE, COMPONENTS, AND OPERATIONALIZATION OF IMPLICIT APTITUDE

In this section, we attempt to identify the nature of implicit language aptitude based on the literature on implicit learning and language aptitude. We then discuss the possible components the construct comprises and tests or tasks that have been or can be used to measure the components.

**NATURE*****Componential or Unitary***

As with explicit aptitude, which consists of three components—phonetic coding, analytic ability, and memory—implicit aptitude is likely componential. The componential nature of implicit aptitude is supported by SLA research showing that measures of implicit aptitude such as LLAMA\_D and SRT have been found to be uncorrelated, and they are predictive of different aspects of learning (Granena, 2019). Likewise, in psychological research, the outcomes of different implicit learning tasks (SRT, artificial grammar [AG], and process control tasks such as sugar production) are found to be uncorrelated (Conway & Christiansen, 2005), which led to “a modular view of implicit learning” (Gebauer & Mackintosh, 2007, p. 48), that is, it is not a unitary construct. Siegelman et al. (2017) addressed the potential of statistical/implicit learning as an individual difference variable predicting learning outcomes and identified the lack of correlations between tasks measuring statistical/implicit learning abilities as one of the most striking characteristics of the construct. To overcome the possible confusion over the construct and operationalization of statistical/implicit learning ability and to recognize the multidimensionality of the construct, Siegelman et al. recommended that researchers formulate a mapping sentence defining the construct they intend to investigate. The following is an example mapping sentence, where the researcher would need to make a choice between the two underlined key words in each pair when developing tests of implicit aptitude:

Implicit aptitude is the ability to learn the distributional/transitional relationships between adjacent/non-adjacent structures in verbal/nonverbal stimuli in the visual/auditory modality. (Adapted from Siegelman et al., 2017, p. 4).

Given the domain-specific nature of SLA, in addition to clarifying the content validity from the perspective of the predicting variable, it is necessary to include the criterion variable in the equation, that is, whether the outcome that implicit aptitude is hypothesized to predict is general L2 proficiency or specific aspects of L2 learning such as L2 skills—listening, reading, speaking, and writing—and L2 knowledge, namely, pronunciation, grammar, or vocabulary.

***Domain-general or Domain-specific***

Theorists entertaining a usage-based approach (Ellis & Wulff, 2015) or the Declarative-Procedural model (Ullman & Lovelett, 2018) both argue that language learning is nothing special and is supported by cognitive abilities that are also important for learning other academic skills. For example, Ellis and Wulff (2015) stated that L2 learners employ “cognitive mechanisms that are not exclusive to language learning, but that are general cognitive mechanisms at work in any kind of learning” (p. 76). To a certain extent, this claim has been confirmed in the research, which demonstrates that implicit aptitude measured through tasks that are seemingly unrelated to language learning, such as SRT (Granena, 2013) and Weather Prediction (Morgan-Short et al., 2014), is predictive of language learning. However, in the paradigm of explicit learning, explicit language

aptitude has been found to be distinct from intelligence or abilities for general academic learning, although they are correlated (Li, 2016; Wen et al., 2019). Explicit language aptitude has also been found to be dissociable from working memory (Yalçın et al., 2016), a domain-general cognitive device for all kinds of learning such as math, chess-playing, sports, and so forth. Based on the same logic, implicit language learning abilities may also differ from abilities for general implicit learning, and there has been initial evidence for such a claim. For example, SRT, which measures sequence learning, has been found to be correlated only with the learning of grammar structures involving agreement between adjacent items (e.g., adding *-s* to an English verb after a third-person singular subject) but not structures governing form-meaning relationships (e.g., using the subjunctive mood to describe unreal situations) (Granena, 2013). Therefore, we argue that implicit aptitude consists of both domain-general implicit learning abilities and domain-specific abilities that are exclusively important for language learning.

### *Relation with Explicit Aptitude*

First, implicit and explicit aptitude are separate constructs. Implicit aptitude measured through SRT, LLAMA\_D, AG, phonetic sensitivity, and tasks of procedural memory showed no or negative correlations with explicit aptitude measured through the MLAT, LLAMA\_B/\_E/\_F, and other cognitive abilities in the explicit domain such as working memory and intelligence—conscious cognitive abilities for school learning (Gebauer & Mackintosh, 2007; Granena, 2019; Hamrick, 2015; Janacek & Nemeth, 2013; Morgan-Short et al., 2014; Reber et al., 1991; Robinson, 2005; Saito et al., 2019; Suzuki & DeKeyser, 2017). Robust evidence for a separation between implicit and explicit cognitive abilities also comes from psychological research showing that patients with cognitive deficits in explicit learning such as amnesia and autism have intact implicit learning abilities (see Williams, 2009 for a review). In a similar vein, subjects with disabilities in implicit learning such as those suffering from dyslexia show that their abilities for explicit learning are unaffected (Jiménez-Fernández et al., 2011). Second, implicit and explicit aptitude play different roles in SLA. Explicit aptitude is more predictive of initial learning while implicit aptitude is more important at later stages (Hamrick, 2015; Morgan-Short et al., 2014). Implicit aptitude is more facilitative of complex linguistic structures, while explicit aptitude is better at assisting with simple structures (DeKeyser, 1995, 2016). Furthermore, there may be interaction between instruction, aptitude, and the linguistic target. For example, in the absence of explicit instruction, learners may draw on explicit aptitude if the structure is salient and on implicit aptitude if it is nonsalient and abstract and involves opaque form-meaning mapping, in which case it is beyond the processing capacity of explicit aptitude (i.e., too complicated to learn explicitly or analytically) (Li, 2013a, 2013b).

### *Age*

Evidence suggests that adults are better than children on at least some implicit learning tasks, such as the SRT (Hodel et al., 2014; Thomas et al., 2004) or AG (Saffran, 2001). Therefore, similar to explicit aptitude (analytic ability, memory, etc.), implicit aptitude seems developmental. This finding seems to contradict some interpretations of the Critical

Period Hypothesis and the Fundamental Difference Hypothesis, which state that child language learners may achieve nativelike proficiency but adults cannot. This is because children have full access to implicit aptitude that enables them to learn a language efficiently and unconsciously while adults have lost at least part of the ability and they must largely rely on explicit aptitude instead (DeKeyser, 2000; Long, 2015). How can we account for the disparity between the theories and the empirical evidence? One possible explanation is that it is not so much the ability for implicit learning in general that decreases with age, but rather (a) more specific component(s) that diminish(es): the kind of implicit aptitude necessary for learning complex, nonsalient, and abstract patterns from unstructured linguistic input. A similar argument was made by Arciuli (2017), who contended that statistical (implicit) learning is a multicomponential construct such that some components may peak earlier than others. Thus, children and adults may excel in different components of implicit learning. Arciuli mentioned the idea of implicit working memory—short-term memory that operates outside of awareness—which is likely implicated in the psychometric tasks used in the research. Adults have larger working memory capacities than children, which is probably why they show better performance in those tasks. It is also possible that the kind of ability children are equipped with is different from the abilities measured through some of the psychometric tasks. The implicit learning ability children have is domain specific in that it is exclusive to language acquisition while the cognitive abilities measured through SRT, Tower of London, Sugar Production, Weather Prediction, and so forth have been claimed to be domain-general abilities that are essential for learning all skills, not just language.

### *Experience*

Whether learning experience contributes to implicit aptitude is controversial, but recent research seems to show that more experience leads to stronger implicit aptitude. Granena (2013) found that early bilinguals (age of onset: 3–6) performed significantly better on LLAMA\_D than late bilinguals (age of onset: 16–30); early bilinguals also outperformed late bilinguals on an SRT, although the difference was nonsignificant. Using an experimental design, Potter et al. (2017) investigated the impact of language learning experience on the improvement of statistical learning ability (implicit aptitude). They recruited two groups of learners, one studying Mandarin as a foreign language and one with no experience with Mandarin. The two groups were tested twice on their statistical learning ability using a verbal test and a nonverbal test. The two groups showed no significant differences at time one but 6 months later, the Mandarin learners did significantly better on the verbal test of statistical learning than the other group. These two studies seem to suggest that language learning experience may increase implicit aptitude, similar to explicit aptitude (see Li, 2016 for a review). However, more empirical evidence is needed to verify the preliminary findings.

### **COMPONENTS AND MEASURES**

Based on the research and theoretical conceptualization, we propose that implicit aptitude consists of the following components: sensitivity to frequency and conditional probability, priming or tendency to be influenced by recent events, and selective attention. The

component of sensitivity to frequency and conditional probability is a core component of implicit aptitude. It refers to the ability to implicitly learn the patterns and regularities underlying stimuli to which one is exposed. The two subcomponents, frequency and conditional probability, which are called distributional statistics and transitional probability respectively in the paradigm of statistical learning, are related but not identical. Frequency refers to the number of times an event occurs, but it does not represent the relationship between events. For example, two words (such as “the man”) that co-occur frequently may not have a strong bond between them because both happen to be high-frequency words. Conditional probability refers to the likelihood and consistency of the co-occurrence of multiple events; it concerns how likely one event is predicted by another event; and it is a matter of dependency or contingency. The component of sensitivity to frequency and conditional probability has been operationalized in different ways in different paradigms.

In the paradigm of “implicit learning,” it is measured through SRT (Nissen & Bulemer, 1987) and AG (Reber, 1993). SRT and AG have generated a large body of research on implicit learning in the field of psychology, but in psychological research they have been used primarily as learning tasks, not as measures of the ability for implicit learning. In a typical SRT task, learners respond to a symbol (e.g., a dot) that appears in different locations, and the order in which the symbol appears is based on a regular (more frequent) and control (less frequent) numeric sequence. Learners’ performance is represented by the differences between reaction times to the target and control sequences. In SLA research, SRT has been used as a standard measure of implicit language aptitude, and it is one of the three subtests (the other two being phonological short-term memory and rote memory) of the recently validated Hi-LAB aptitude battery that were significantly predictive of high-level proficiency (Doughty, 2019; Linck, 2013). In an AG task, learners are asked to memorize some letter strings based on a finite grammar that specifies the paths for the combinations and transitions of the strings, and then they are given a test asking them to recognize grammatical and ungrammatical strings based on what is learned in the exposure phase. The abilities measured by SRT and AG tasks can be called sequence learning because they concern the learning of regularities that govern how symbols and stimuli are sequenced. Among existing measures of implicit aptitude, sequence learning is of particular relevance to language learning because it pertains to learning the consistent co-occurrence of entities or symbols, characterized by linearity, contingency, and arbitrariness—defining characteristics of human languages.

In the paradigm of the Declarative-Procedural model, sensitivity to frequency and conditional probability has been conceptualized as procedural memory, which stores information about rules and patterns applied in skill performance. In tasks of procedural memory, subjects are asked to reach a goal or maintain a certain target based on presented stimuli and to receive feedback on their responses, with a view to enabling them to implicitly learn the regularities underlying the input. These tasks can be collectively called process control tasks or tasks of dynamic system control (Gebauer & Mackintosh, 2007). One example is the Tower of London task used by Morgan-Short et al. (2014), where subjects are given an initial configuration of pegs and balls and then convert it to a target arrangement or end state. Another example is “sugar production,” where subjects are required to manage the input (number of workers employed) and output (production of sugar) of an imaginary sugar factory in a computer game. Unbeknownst to subjects is that

the trials are guided by a formula. The relationship between input and output is nonlinear and yet subjects are able to detect the patterns. Gebauer and Mackintosh (2007) reported that process control, measured using two tests called “sugar factory” and “computer person,” was uncorrelated with SRT and AG but significantly correlated with fluid intelligence (explicit aptitude), casting doubt on the convergent and divergent validity of process control as a measure of implicit aptitude.

In the field of statistical learning, the interest in implicit learning started with the investigation of infants’ ability to identify word boundaries based on the regularities they unconsciously extrapolate from the auditory stimuli they are exposed to, such as non-words or syllable strings (Saffran et al., 1996). One strength of the tasks in statistical learning is that the input stimuli are typically words and syllables created based on the phonotactic rules of natural languages. In the field of SLA, LLAMA\_D, which has sometimes been considered a measure of implicit aptitude, is similar to the tasks used in research on statistical learning. In this test, subjects listen to some nonexistent syllables in the learning phase, and then during the testing phase, they listen to some sound sequences again and recognize whether the sequences are new or old. Another test that falls into this category and that has the potential of a measure of the ability for implicit vocabulary and pronunciation learning is called phonological sequencing (Speciale et al., 2004). During the test, subjects are repeatedly exposed to some nonwords that are two to four syllables long together with some distractors. They are then asked to recognize familiar and unfamiliar items. Speciale et al. found it to be distinct from phonological short-term memory (explicit aptitude) and significantly predictive of second language receptive and productive vocabulary learning. The researchers referred to this test as a measure of “implicit induction of phonological sequences, ... which contribute to at least three facets of lexical development: the segmentation of speech into discrete word units, identification of the lexical units of language, and the development of automaticity in their processing” (p. 294).

One possible limitation of these tests is that they do not appear related to language learning, which involves the mapping between form and meaning. The stimuli in some of these tasks such as SRT, AG, and LLAMA\_D involve sequences and syllables, but they are semantically vacuous. Other tasks such as Tower of London, which was intended as a test of planning ability (Kaller et al., 2012), are totally unrelated to language learning. These tasks at best measure domain-general implicit learning abilities. However, language involves both form and meaning, and it is a system that consists of symbolic as well as semantic representations. Language learning entails not only extrapolating the linear relationship between units and symbols but also the abstraction of how they vary, combine, and configure to represent and encode meaning, namely form-meaning mapping. There are two possible ways to incorporate elements of language learning in the measurement of implicit aptitude. One is to incorporate a meaning component in existing domain-general tasks such as AG. Another is to use separate measures involving form-meaning mapping, such as the type used by Rebuschat (2008) and Williams (2005), where the learning target was built in sentences in the subjects’ first language. However, these kinds of tasks may make the target structure salient and encourage explicit learning.

One way to add a meaning component and minimize explicit learning is to use a priming task. Priming, which measures the tendency to be influenced by previously experienced input, is a possible ideal measure of implicit language aptitude. The idea of

priming is that one's performance in a current event is facilitated by a previous encounter with a similar or same event (Bock, 1986). For example, after hearing the sentence "The father gave a present to his daughter," one is more likely to say, "The teacher gave a book to the student," even though "The teacher gave the student a book" is equally correct. Thus, learners' performance on such tasks represents their ability to incorporate or appropriate linguistic input they were exposed to in previous experiences. Different from sequence learning (SRT, AG, etc.), which relies on frequency and repeated processing of the same input, priming may happen even with one encounter. Priming is considered a measure of implicit memory in cognitive psychology (Goldstein, 2011; Knowlton & Greenberg, 2008). Priming can be divided into auditory priming, semantic priming, and syntactic priming (exemplified in the preceding text) (McDonough & Trofimovich, 2008). As an example of auditory priming, people are more likely to produce the word "elephant" than "element" when asked to complete "ele\_\_\_\_," after they heard the word "elephant" together with other unrelated words. To exemplify semantic priming, after hearing the word "furniture," one would respond faster when asked to spot the item that does not belong to the group of objects: bed, chair, table, and cow, compared with an unprimed situation in which the subject heard the word "satellite" before seeing the same group of items. In SLA, semantic priming has been used as a measure of aptitude (Granena, 2019; Linck, 2013). Syntactic priming is potentially a valuable addition to aptitude measurement due to its integration of meaning and form and to its possible unique contribution to learning attainment because of its distinctness from existing measures.

The third component of implicit aptitude is selective attention—the ability that "allows us to pick up behaviorally relevant information and ignore vast amounts of irrelevant information" (Jiang & Chun, 2001, p. 1105). A common assumption about implicit learning is that it must happen without learners' awareness of either the process or outcome of learning. Awareness is often elicited through learners' self-reports of whether they can verbalize rules underlying learning materials. While awareness is a criterion for vetting implicit learning, attention is required for any learning to happen. As Perruchet (2008), a leading figure in implicit learning, observed: "Without at least minimal attentional involvement, even simple covariations or regularities turn out to be impossible to learn" (p. 610). Selective attention is also a key element in the learning mechanism advocated in the Interaction Hypothesis (Gass, 2018; Long, 2015). The importance of attention for implicit learning has been borne out in research. For example, Shanks et al. (2005) demonstrated that double-task conditions in SRT where subjects' attention was split between two tasks affected performance negatively. Jiang and Chun (2001) used the contextual cuing paradigm to show that implicit learning was effective only when relevant predictive information was selectively attended to. Hoffmann and Sebald (2005) further showed that in covariation learning, even when the covariations to be learned were highly salient, no learning occurred without attention. Here we would like to clarify two issues. First, there are different levels of attention, such as alertness, orientation, registration, detection, and understanding. The level of attention needed for implicit learning is likely minimal, such as apperception in Gass's (2018) conceptualization, which refers to the registration of incoming stimuli. A higher level of attention, detection, may or may not be necessary depending on the saliency of the structure and nature of the input material. Second, here the function of attention is to select, not to store, information, hence the term

selective attention. Selective attention does not require mental capacity or effortful processing of input (Frensch & R nger, 2003), and once input is attended to, it will be processed implicitly. As Kaufman et al. (2010) stated:

For implicit learning to occur, selective attention to the relevant stimuli is required. However, learning about the stimuli that are selectively attended to then occurs automatically, regardless of an intention to learn, and without necessitating any further executive processing resources. (p. 323)

How can selective attention be measured? In the literature, it is integrated into tasks of implicit learning, such as by including a secondary task asking the subject to count the number of high-pitched tones while performing an SRT or AG task (Nissen & Bulemer, 1987), or by building in another learning task, for example, in an SRT task, the locations of the stimuli are not only based on a finite grammar but also on shapes (Jim nez & M ndez, 1999). Because the focus here is the role of selective attention in implicit learning, it stands to reason to measure it as part of the construct of implicit aptitude, rather than measure it in isolation as in tests of the executive functions of working memory such as inhibition, updating, and shifting (Miyake & Friedman, 2012). Thus, we advocate an integrated rather than independent approach to the measurement of selective attention when investigating implicit aptitude.

## IMPLICIT APTITUDE AND SECOND LANGUAGE ACQUISITION

To date, there has been limited research on implicit aptitude's associations with L2 learning. The limited research can be roughly divided into two categories based on the research setting: naturalistic and instructed. In a naturalistic setting, the target language is also the language of the community, and learners have opportunities for exposure to the L2 in their everyday life. An instructed setting is one where L2 learning happens primarily in the classroom, whether virtual or physical. The studies conducted in naturalistic settings can be subdivided into two groups. One group investigated the associations between aptitude and the ultimate attainment of learners who arrived in the country of the L2 at different ages. These studies were conducted with learners who had lived in the country of the L2 for at least 8 years. Granena (2013) investigated whether implicit aptitude measured by SRT and LLAMA\_D was correlated with the ultimate attainment of early and late bilinguals. It was found that SRT was predictive of late bilinguals' implicit knowledge measured through a word-monitoring task, while LLAMA\_D was predictive of early bilinguals' explicit knowledge assessed using a grammaticality judgment test (GJT). Other age-related studies that only included explicit aptitude shed further light on the interface between age and aptitude. DeKeyser's (2000) seminal study showed that explicit aptitude measured by the Words in Sentences subtest of the HUNLAT (a measure of language analytic ability) was predictive of late, but not early, bilinguals' scores on an aural GJT. Abrahamsson and Hyltenstam (2008) only investigated L2 learners who passed for native speakers. They reported that (a) late bilinguals all had high aptitude (measured using an early version of LLAMA) while early bilinguals and native speakers showed varied levels of aptitude; and (b) aptitude showed a significant correlation with early bilinguals' scores on a challenging GJT ( $r = .70, p < .01$ ) and a near-significant correlation with late bilinguals' GJT scores ( $r = .57, p = .09$ ). Granena and Long (2013)

explored aptitude's associations with Chinese speakers' L2 Spanish proficiency. They found that total LLAMA scores, which mainly represent explicit aptitude, correlated with late bilinguals' (age of onset > 16) vocabulary and pronunciation, but not early bilinguals' (age of onset: 3–6) Spanish proficiency. These studies suggest that explicit aptitude is more likely to be involved in late bilinguals' L2 attainment and implicit aptitude is drawn upon by both early and late bilinguals. However, the conclusion is not unequivocal because of the disparate findings of the research.

The other group of naturalistic studies investigated the predictive power of implicit aptitude for the L2 proficiency of learners who arrived in the country of the L2 during adulthood. These studies involved learners who had lived in the country of the second language for less than 3 years (Saito et al., 2019; Suzuki & DeKeyser, 2015, 2017; Yi, 2018). One commonality between the studies is that they all examined L1 Chinese speakers, and the homogeneity of the learners' L1 background, albeit coincidental, may increase the robustness of the findings. These studies afford further insights into aptitude-learning associations in naturalistic settings. Saito et al. (2019) explored whether Chinese speakers' implicit and explicit phonetic aptitude was associated with their L2 English speech performance. They used an electrophysiological method to measure implicit aptitude and LLAMA\_E and a test of music aptitude (abilities to discriminate melody and rhythm) to measure explicit aptitude. They reported significant effects for both types of aptitude on L2 pronunciation learning. Saito et al.'s study is seminal in that it is among the first to investigate implicit and explicit pronunciation aptitude in L2 speech performance. The study also proposed a framework mapping the relationships between implicit and explicit pronunciation aptitude and segmental (sounds) and suprasegmental (word stress, rhythm, etc.) accuracy. The two studies by Suzuki and DeKeyser examined L1 Chinese speakers' L2 Japanese proficiency, and the primary objective of the studies was to explore the relationship between implicit and explicit knowledge by drawing on the concept of implicit and explicit aptitude. Taken together, the two studies revealed that (a) implicit aptitude measured by SRT was positively correlated with long-residence learners', but not short-residence learners', implicit knowledge of L2 Japanese morpho-syntax measured using a word monitoring test; (b) SRT was negatively, albeit nonsignificantly, correlated with short-residence learners' implicit knowledge; and (c) explicit aptitude measured by LLAMA\_F was predictive of explicit knowledge (automatized). Yi (2018) demonstrated that in a U.S. context, L1 Chinese L2 English speakers' knowledge about English collocations was significantly correlated with their explicit aptitude (LLAMA\_B/\_E/\_F) but not their implicit aptitude (SRT).

What do we make of the results of these naturalistic studies? As can be seen, the results are quite mixed, but overall the following patterns can be extracted. First, implicit aptitude is predictive of naturalistic L2 learning, but its effects seem more likely to be evident in learners who have resided in the country for longer periods (Granena, 2013; Suzuki & DeKeyser, 2017). Second, explicit aptitude is predictive of late, but not early, bilinguals' L2 attainment (Granena & Long, 2013; Suzuki & DeKeyser, 2015; Yi, 2018), but there are exceptions (Abrahamsson & Hyltenstam, 2008). Third, the relationship between implicit and explicit knowledge and implicit and explicit aptitude is unclear.

Next, we proceed to the studies on instructed learning. We further divide these studies into two categories: correlational and experimental. In correlational research, there is no instructional treatment, and the interest is in whether aptitude is correlated with L2

proficiency. (In this sense, all the naturalistic studies are correlational.) In experimental research, learners receive instructional treatments, and the objective is to show whether aptitude is drawn on differently under different learning conditions. Starting with correlational research, Granena's (2019) study involved learners of Spanish whose native language is English at a large U.S. university. The researcher administered the Hi-LAB aptitude battery and the LLAMA tests and explored the relationship between explicit and implicit aptitude and L2 speech performance coded as complexity, accuracy, and fluency. The study showed no effects for explicit aptitude (LLAMA\_B/\_E/\_F + MLAT\_5 + Letter Recall) and a significant effect for implicit memory (semantic priming + LLAMA\_D) on fluency. An interaction between implicit memory and SRT—a measure of implicit aptitude—was found such that implicit memory was important for lexical complexity only among learners with high SRT scores. Link et al.'s (2013) seminal study attempted to identify cognitive abilities for high-level proficiency operationalized as L2 Spanish speakers' listening and reading scores on a proficiency test and their high-level job performance in the L2. The researchers reported that among the 13 measures of cognitive ability, implicit aptitude (SRT), phonological short-term memory, and rote memory were significant predictors. Saito et al.'s (2019) study, conducted with Japanese learners of English in Tokyo, reported that explicit aptitude (LLAMA\_B and \_E) was predictive of learners' speech fluency during their first semester's study, whereas implicit aptitude (LLAMA\_D) showed an important effect on their pronunciation development in the second semester.

In the experimental research, the studies by Yilmaz and Granena (Granena & Yilmaz, 2019; Yilmaz & Granena, 2019) investigated whether explicit and implicit aptitude fared differently when L1 English L2 Spanish learners at a large U.S. university received explicit and implicit feedback. They found that implicit aptitude (SRT) was correlated with the effects of implicit feedback, and explicit aptitude operationalized as phonological short-term memory was predictive of the effects of explicit feedback. The significant results for implicit aptitude were only obtained for the gender agreement, not the other target structure—object case marking. The studies by Hamrick (2015) and Morgan-Short et al. (2014) were conducted within the framework of the Declarative/Procedural model. In Morgan-Short et al.'s study, native speakers of English learned an artificial language in an incidental condition—they were never taught grammar rules, and they learned the language by engaging in meaning-oriented comprehension and production activities. They took two tests of procedural memory (implicit aptitude) (Tower of London and Weather Prediction) and two tests of declarative memory (explicit aptitude) (MLAT\_5 and CVMT). Treatment effects were measured twice using a GJT: after the first two treatment sessions and after all four treatment sessions. It was found that declarative memory was predictive of the first posttest scores and procedural memory was correlated with the second posttest scores. Hamrick (2015) also examined the role of procedural and declarative memory in incidental learning, but the memory tests (SRT and LLAMA\_B, respectively) and learning task (three Persian structures built into English sentences) were different from those in Morgan-Short et al.'s study. Significant effects were found for declarative memory on the learners' posttest scores immediately after the treatment, and for procedural memory on their scores on a delayed posttest (administered 2 weeks after the treatment). Both Morgan-Short et al. and Hamrick claimed that their studies showed that declarative memory is relevant at initial stages of L2 learning and procedural memory at later stages.

To summarize the research on instructed learning, we can observe the following patterns. First, the correlational studies showed that implicit aptitude is predictive of foreign language learners' *speech performance* (Granena, 2019; Saito et al., 2019) and *high-level proficiency* in listening and reading comprehension (Linck, 2013), suggesting implicit aptitude's links with implicit knowledge, which is probably represented in both outcome measures. Second, the experimental studies showed that under highly controlled incidental learning conditions, learners are more likely to draw on explicit aptitude initially and implicit aptitude at later stages (Hamrick, 2015; Morgan-Short et al., 2014). In this case, the learners were exposed to artificial languages and had zero knowledge about the target languages. The studies conducted with learners with some previous knowledge about the target language (Spanish) demonstrate that learners draw on implicit aptitude when receiving implicit instruction and explicit aptitude when receiving explicit instruction (Granena & Yilmaz, 2019; Yilmaz & Granena, 2019). However, due to limited research, the results need to be interpreted with reference to the idiosyncratic methodological features of these studies. For example, in the case of the studies by Granena and Yilmaz, the results may have changed if an analytic measure of explicit aptitude was used and/or if the explicit feedback was operationalized as metalinguistic feedback rather than explicit correction. Also, the research examined a narrow range of target structures, and there may exist an interaction between aptitude type and the target structure (DeKeyser, 2012; Li, 2014). Therefore, at this point, no firm conclusions can be reached, and further research is needed before a clear picture can be provided. The lack of clear and consistent findings in this research area so far is an incentive for this special issue.

### THE SPECIAL ISSUE

To date, the research on cognitive abilities for second language learning has been dominated by explicit aptitude, which requires effortful and conscious encoding, processing, storage, and retrieval of linguistic input. There has been little theorization and research on implicit aptitude. The study of implicit aptitude is challenging because of the elusive and uncontrolled nature of implicit learning and the resultant difficulty in designing tasks to capture its effects and gauge the underlying ability. This special issue takes the challenge by contributing seven empirical studies examining implicit aptitude from various perspectives with a view to drawing attention to this newly emerged construct, exemplifying ways to examine the construct, and deepening our understanding of its nature and mechanism. In the following, we provide an overview of the seven included studies and discuss in what way they contribute to the study of implicit aptitude.

Buffington, Demos, and Morgan-Short examined the convergent and divergent validity of tasks/tests of procedural memory, which we equate with implicit aptitude. Convergent validity refers to whether the tasks purported to measure the same construct—procedural memory in this case—are correlated with each other, and divergent validity refers to whether the tasks of procedural memory are uncorrelated or less strongly correlated with measures of declarative memory, which is theoretically distinct from procedural memory. Ninety-nine undergraduate students at a large U.S. university completed three tasks for procedural memory and three for declarative memory. Procedural memory was tested through SRT, weather prediction, and Tower of London. Declarative memory was

measured using a test of rote memory (MLAT\_5) and two memory recognition tasks: Continuous Visual Memory Test (CVMT) and Declearn. The results showed that (a) CVMT, Declearn, and weather prediction loaded onto the same factor, (b) SRT loaded onto another factor, and (c) the other measures did not have acceptable factor loadings in any factor. These results were unexpected in that weather prediction was intended to be a measure of procedural memory but loaded onto the factor of declarative memory and that the three measures of procedural memory were uncorrelated with each other. The results suggested a lack of convergent validity of the procedural memory tasks, and a lack of divergent validity of the weather prediction task. Based on the results, the researchers suggested not using weather prediction as a measure of procedural memory and having a clear notion of what kind of ability is intended to be tapped when using a particular test in future research.

Fu and Li's contribution is an ATI (aptitude-treatment-interaction) study investigating the complicated relationship between types of aptitude and types of treatment. It examined whether implicit aptitude operationalized as procedural memory and explicit aptitude as declarative memory and working memory have differential associations with the effectiveness of immediate and delayed corrective feedback. The subjects were 112 seventh-grade EFL learners, who were divided into three groups and received immediate, delayed, or no feedback, depending on their group assignment. Immediate feedback was provided during a communicative task immediately after the learners received grammar instruction about the target structure (the English past tense), and delayed feedback was provided 2 weeks after the initial grammar instruction and after the learners completed some communicative practice. Treatment effects were tested using a GJT (explicit knowledge) and an elicited imitation test (implicit knowledge). Procedural memory was measured through a SRT task, declarative memory was tested by means of a memory recognition task, and working memory was gauged using an operation span task. It was found that procedural memory was predictive of the effects of immediate feedback, declarative memory was associated with the effects of delayed feedback, and working memory was involved in both immediate and delayed feedback. The significant effects were evident only on the elicited imitation test, not the GJT. The results suggested that the three types of memory have differential relationships with different instructional treatments. Fu and Li argued that the role of procedural memory was evident in immediate feedback probably because (a) learners had sufficient declarative knowledge that resulted from the grammar instruction and was solidified through immediate feedback, and (b) immediate feedback may have expedited the proceduralization of declarative knowledge by drawing learners' attention to the target structure. Declarative memory was predictive of the effects of delayed feedback because the feedback prompted learners to draw on their declarative memory to retrieve the declarative knowledge obtained through the grammar instruction provided two weeks ago and to learn new declarative knowledge from feedback. Working memory was implicated in both feedback conditions because of the heavy processing load imposed on learners by online feedback provided during task performance (Li et al., 2019). Finally, the mapping between implicit and explicit aptitude and implicit and explicit knowledge was unclear, similar to what transpired in Yilmaz and Granena's study (see following text).

Godfroid and Kim's study aimed to map the relationship between implicit aptitude and implicit and explicit knowledge. One hundred and thirty-one ESL learners at a large

U.S. university whose average length of residence in the country was 41 months took two tests of implicit knowledge: word monitoring and self-paced reading; four tests of automatized explicit knowledge: timed aural grammaticality judgement (GJT), timed written GJT, elicited imitation, and oral production; and three tests of explicit knowledge: untimed aural GJT, untimed written GJT, and metalinguistic knowledge. They also took four tests of implicit aptitude: sequence learning (SRT), auditory statistical learning, visual statistical learning, and Tower of London. The results showed poor convergent validity of the measures of implicit aptitude—they were largely uncorrelated—except for a strong correlation between the two measures of statistical learning. The researchers also examined the measurement model for the proficiency measures, testing a two-factor model (implicit knowledge and explicit knowledge) and a three-factor model (implicit knowledge, explicit knowledge, and automatized explicit knowledge). They found better fit indices for the two-factor model and therefore elected to follow that model in further analyses. In a subsequent structural equation modeling analysis, a significant, positive path was detected between sequence learning and implicit knowledge, and no other paths were significant. The findings showed a lack of correlations between different measures of implicit aptitude and the robustness of sequence learning as a predictor of L2 attainment compared with other measures of implicit aptitude.

Li and Qian explored syntactic priming as a measure of implicit aptitude. The study is motivated by the semantic vacuity of existing measures and the fit of the mechanism of syntactic priming with the mechanism of language learning. One hundred sixty-six L2 English learners at a Chinese university were given three tests of implicit aptitude: priming, SRT, and LLAMA\_D; three tests of explicit aptitude: LLAMA\_B, \_E, and \_F; two tests of explicit knowledge: GJT and metalinguistic knowledge; and one test of implicit knowledge: elicited imitation. The three measures of implicit aptitude failed to show convergent validity. LLAMA\_D loaded onto the factor of explicit aptitude, and syntactic priming was negatively correlated with sequence learning. Structural equation modeling analyses mapping the relationships between aptitude and proficiency measures showed that syntactic priming was a negative predictor of metalinguistic knowledge, sequence learning was not a significant predictor of any proficiency measure, and explicit aptitude was a strong predictor of L2 proficiency. The proficiency factor comprised all three outcome measures including elicitation imitation, which was hypothesized to measure implicit knowledge. The findings provided further evidence for the multidimensional and multicomponential nature of implicit aptitude. The researchers interpreted the findings by comparing the different mechanisms of sequence learning and priming, highlighting the need for further research into the validity of priming as a measure of implicit aptitude. The researchers also discussed the challenge in assessing the implicit knowledge of learners in a foreign language setting where the instruction is heavily form oriented, which may lead to knowledge that is primarily explicit. This explanation sheds light on the disparity between the findings of Li and Qian's study and Godfroid and Kim's study where implicit and explicit knowledge were separable and a positive link was found between sequence learning and automatized explicit L2 knowledge. Although the designs of the two studies are similar, Li and Qian's study was conducted in a foreign language setting while Godfroid and Kim's study involved learners in a naturalistic setting where implicit or automatized explicit knowledge is more likely to develop. Although the validity of syntactic priming as a measure of implicit aptitude was not established, the

study contributes insights into the methods of aptitude research and the potential for further research on the topic.

Sun, Saito, and Tierney investigated the associations between implicit and explicit auditory processing abilities and L2 speech perception in a naturalistic setting. The subjects were 46 L1 Chinese L2 English learners in London who had lived in the country for around five months. Explicit auditory processing was measured by means of two auditory processing tests: sound discrimination threshold and music memory, and implicit auditory processing was gauged through a test of neural encoding of sound. The sound discrimination threshold test asked learners to distinguish sounds varying in pitch, formant, duration, and amplitude rise time. In the test of music memory, learners were required to repeat a melody or rhythm to which they listened. In the test of implicit auditory processing, learners listened to a /da/ sound for 20 minutes while reading a book or magazine. Electrodes were placed on their heads to record their electrophysiological responses, which then served as a proxy of their neural encoding of sound. Speech perception, the outcome variable, was measured through a minimal pair sound recognition test at two time points with an interval of five months. The learners made significant improvements only in prosody perception but not in vowel perception, which was not further analyzed. The results demonstrated that music memory was the only significant predictor of prosody perception. The researchers interpreted the findings as suggesting that explicit aptitude is important at an initial stage of immersion, that the learners' length of residence is not long enough for the effect of implicit aptitude to be evident, and that implicit aptitude may be important for the segmental (not analyzed because of ceiling effects) but not suprasegmental (prosody) perception. This study represents an attempt to investigate the domain-specific nature of implicit aptitude in that it examined the associations between pronunciation aptitude and pronunciation learning. It also exemplifies how implicit aptitude can be gauged through a neurological measure—an innovation in aptitude research. The finding confirms the findings of existing naturalistic studies that short-residence learners draw on explicit aptitude (Yi, 2018) and that implicit aptitude only plays a role in the L2 gains of long-residence learners (Granena, 2013; Suzuki & DeKeyser, 2015). However, the study did not include a measure of implicit knowledge, which could have correlated with implicit aptitude.

Suzuki's study seeks to improve the validity of LLAMA\_D as a measure of implicit aptitude. Fifty-nine L1 Japanese university students took LLAMA\_D and the other three subtests (LLAMA\_B, \_E, and \_F) that were purported to measure explicit aptitude, and they also completed an oral production task in L2 English. During the LLAMA\_D, the participants were asked to listen to 20 disyllabic sounds, followed by a testing phase where they listened to the old sounds as well as 10 new sounds and decided whether each was old or new. To encourage incidental learning, the instructions for LLAMA\_D were modified, requiring the learners to check the sound volume while listening to the sound stimuli and not informing them of the subsequent test phase. The learners were asked to rate their confidence levels for their responses when asked to recognize whether an item was an old or new item in the testing phase. The study found that LLAMA\_D was separate from the other LLAMA subtests; the participants' responses to old and new items represented separate processes; the participants' confidence ratings were related to the accuracy and reaction time of their responses, suggesting that they were conscious of what they learned; and the CV (coefficient of variance) of the reaction time measure of LLAMA\_D was

significantly predictive of the mid-clause fluency of the learners' L2 speech performance—a measure of implicit knowledge. Based on the results, the researcher recommended separating the old and new items of LLAMA\_D, using the instructions that encouraged incidental learning, and calculating the CV of reaction time in future research.

Yilmaz and Granena conducted a complicated ATI study examining the double-dissociation hypothesis, that is, implicit aptitude will correlate with the effects of implicit instruction but not the effects of explicit instruction, and explicit aptitude will correlate with the effects of explicit instruction but not the effects of implicit instruction. One hundred thirteen L2 Spanish learners at a U.S. university were divided into three groups—explicit feedback operationalized as explicit correction, implicit feedback that took the form of recasts, and control, who only performed treatment tasks without receiving any feedback. The target structures were Spanish noun-adjective gender agreement and differential object marking (DOM). The aptitude measures included the LLAMA aptitude battery and several subtests of the Hi-LAB (Linck, 2013) including phonological short-term memory (PSTM), sequence learning (SRT), semantic priming, and rote memory. The learners completed two information gap tasks in dyadic interaction with the researcher, during which the experimental groups received corrective feedback on their wrong production of the target structures. Treatment effects were measured by means of a GJT, which was intended to be a test of explicit knowledge, and an oral production test, a measure of implicit knowledge. An exploratory factor analysis of the data for the aptitude measures yielded three factors: implicit learning (SRT + PSTM), implicit memory (LLAMA\_D + semantic priming), and explicit aptitude (LLAMA\_B + LLAMA\_E + LLAMA\_F + rote memory). It was found that implicit aptitude in the form of implicit learning was predictive of the effects of implicit feedback on the GJT test in the learning of gender agreement and that explicit aptitude was associated with the effects of explicit feedback in the learning of DOM. The study provides preliminary evidence for the double-dissociation hypothesis. One contribution of the study is the finding that implicit aptitude may potentially be divided into implicit learning ability and implicit memory ability. Another thought-provoking finding is the possible interface between aptitude type and the target structure. Specifically, implicit aptitude in the form of sequence learning was important for gender agreement—a structure that involves agreement between adjacent items and opaque form-meaning mapping. Explicit aptitude, however, was important for DOM, which involves transparent form-meaning mapping (only animacy was manipulated for this structure). Finally, implicit aptitude had a negative correlation with the effects of explicit feedback while explicit aptitude had a negative correlation with the effects of implicit feedback, although both correlations were nonsignificant. This finding constitutes further evidence for the double-dissociation hypothesis.

## CONCLUSION

Aptitude is a core research area in SLA that is responsible for the theorization and empirical investigation of the role cognitive abilities play in the process and product of L2 learning. The advent of implicit aptitude has changed the terrain of aptitude research, prompting researchers to reconsider the findings and implications of previous research, reconceptualize the cognitive foundation of SLA, and collect evidence to validate the construct validity of implicit aptitude. This thematic issue is a timely initiative examining

its construct validity from different perspectives. The research designs encompass correlational studies investigating the predictive power of implicit aptitude for learning success, experimental studies ascertaining the interface between aptitude and treatment effects, and validation studies aiming to examine the convergent, divergent, and content validity of the measures of implicit aptitude. The examined learner samples include classroom learners as well as learners in immersion settings, and adult learners as well as young learners. Based on the studies of the thematic issue and previous research, we would like to make the following recommendations for future research. First and foremost, given the separation between explicit and implicit aptitude, future research would need to distinguish the two types of cognitive abilities theoretically and methodologically and examine their unique and joint effects on L2 development. Second, because of the lack of convergent validity of the measures of implicit aptitude, it is necessary to clarify the nature of the construct theoretically, use measures that match the construct, and include multiple measures to increase the likelihood of accurately capturing the underlying ability/abilities. Based on existing evidence, SRT (sequence learning) has proven to be one of the (if not the) most valid measures of implicit aptitude. Thus, SRT should be prioritized when selecting measures of implicit aptitude. Third, current measures of implicit aptitude are imported intact from cognitive psychology based on the assumption that implicit aptitude is domain general. There is a need to explore whether measures of implicit aptitude need to incorporate features that are unique to language learning because language learning involves form-meaning mapping, unlike the kind of learning that happens in other skill and knowledge domains. Fourth, more experimental research where instruction is manipulated is needed because compared with correlational research, the results of experimental research are more revealing of the mechanism through which implicit aptitude influences the process and outcome of SLA. Finally, the role of aptitude is dynamic and may vary as a function of the learning condition, learners' age, the linguistic target, and so forth. Thus, it is important to examine whether these factors mediate the associations between implicit aptitude and L2 learning and consider the factors when interpreting research findings.

## NOTES

<sup>1</sup>By claiming that implicit aptitude is a trait variable, we mean it is relatively stable and causes individual variation among learners, which in turn may lead to variation in learning outcomes. However, we do not intend to argue that it is unchangeable. In fact, there is preliminary evidence that both implicit and explicit aptitude are subject to experience and increase with age.

<sup>2</sup>The symbiotic relationship between implicit and explicit aptitude is a new topic that needs theoretical clarification and empirical verification.

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