



Child first language and adult second language are both tied to general-purpose learning systems

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Do the mechanisms underlying language in fact serve general-purpose functions that preexist this uniquely human capacity? To address this contentious and empirically challenging issue, we systematically tested the predictions of a well-studied neurocognitive theory of language motivated by evolutionary principles. Multiple metaanalyses were performed to examine predicted links between language and two general-purpose learning systems, declarative and procedural memory. The results tied lexical abilities to learning only in declarative memory, while grammar was linked to learning in both systems in both child first language and adult second language, in specific ways. In second language learners, grammar was associated with only declarative memory at lower language experience, but with only procedural memory at higher experience. The findings yielded large effect sizes and held consistently across languages, language families, linguistic structures, and tasks, underscoring their reliability and validity. The results, which met the predicted pattern, provide comprehensive evidence that language is tied to general-purpose systems both in children acquiring their native language and adults learning an additional language. Crucially, if language learning relies on these systems, then our extensive knowledge of the systems from animal and human studies may also apply to this domain, leading to predictions that might be unwarranted in the more circumscribed study of language. Thus, by demonstrating a role for these systems in language, the findings simultaneously lay a foundation for potentially important advances in the study of this critical domain.

language | learning | domain-general | declarative memory | procedural memory

One of the most historically contentious debates in the study of language is whether the mechanisms underlying this domain are dedicated to it or whether they in fact serve more general functions (1–5). Substantial research has focused on the possibility or assumed that aspects of language depend on “domain-specific” neural, cognitive, or computational underpinnings (2, 5–11). However, the demonstration of domain specificity has proven challenging (3, 4, 12). More recently, increasing attention has been paid to the possibility that language is “domain-general,” that is, that aspects of language rely on substrates with more general functions that may predate the emergence of this domain (13–16), such as categorization (15, 17), associative learning (16), working memory (18, 19), or learning and memory (13, 14). Indeed, it has been argued that because the reuse of preexisting mechanisms for new functions is expected under biological and evolutionary principles, one should expect domain-general mechanisms for language (12–14, 20, 21).

However, domain generality is also challenging, both theoretically and empirically. Theoretically, domain generality (like domain specificity) could be a complex construct. A dependence on general-purpose mechanisms could vary across aspects of language (e.g., lexicon and grammar) (2) and neurocognitive levels (e.g., systems, circuits, and cell assemblies) (12), as well as over the course of learning and development (3, 12, 22) and between first and second language (L1 and L2) (23, 24). For example, it has been suggested that L2 is tied to domain-general mechanisms,

while L1 (especially grammar) relies on language-specific mechanisms (23). Empirically, domain generality is also difficult to demonstrate. Failure to demonstrate a dissociation between any given pair of language and nonlanguage functions may not be due to a common substrate, but rather could be a false negative, for example, from insufficient spatial resolution or statistical power. However, the demonstration of associations between language and nonlanguage functions can also be difficult to interpret. In particular, any given association could in principle be explained by various factors other than a common substrate, or simply by chance.

This problem can be addressed with a well-motivated theory that generates multiple specific predictions regarding which aspects of language depend on which general-purpose systems in which circumstances, since observation of the full pattern of predictions would generally be less likely to be explained by other factors or by chance (*Discussion*). One such theoretical framework is the declarative/procedural (DP) model of language (13, 14). This model is motivated by the principle that in evolution and biology new functions often piggyback on previously existing mechanisms, whether or not these have become further specialized (evolutionarily or developmentally) for the new functions. The DP model simply posits that since most aspects of language must be learned, language should depend heavily on the declarative and procedural learning and memory systems, since these systems may be the two most important learning systems in the brain (13, 14).

If language relies on these learning systems, they should play similar roles in language as in nonlanguage functions—including in the core language functions of lexicon and grammar (13, 14). The medial temporal lobe-based declarative learning and memory

Significance

It has long been debated whether the mechanisms that underlie language are dedicated to this uniquely human capacity or whether in fact they serve more general-purpose functions. Our study provides strong evidence that language—indeed both first and second language—is learned, in specific ways, by general-purpose neurocognitive mechanisms that preexist *Homo sapiens*. The results have broad implications. They elucidate both the ontogeny (development) and phylogeny (evolution) of language. Moreover, they suggest that our substantial knowledge of the general-purpose mechanisms, from both animal and human studies, may also apply to language. The study may thus lead to a research program that can generate a wide range of predictions about this critical domain.

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system (25–27) plays a crucial role in learning idiosyncratic bits of information and their associations, leading to the prediction that it should also play a crucial role in such information in language (13, 14). Thus, the learning and use of lexical knowledge—idiosyncratic knowledge of words and their associated features—should critically rely on declarative memory. The frontal/basal ganglia-based procedural memory system, by contrast, underlies the learning of automatized implicit motor and cognitive skills, and may be specialized for rules and sequences (13, 14, 25–28). Thus, the DP model predicts that this system should play an important role in grammar, which shares these characteristics (13, 14).

However, given the flexibility of declarative memory (25), it, too, should underlie grammatical functions, for example, by learning rules or chunks (e.g., “the cat”) (13, 14). A range of factors could lead to an increased dependence of grammar on declarative memory (13, 14, 24). Of interest here, since learning in declarative memory seems to improve during childhood (with possible concomitant declines in procedural learning and/or consolidation), later learners of language are predicted to depend particularly on declarative memory for grammar, while native speakers should rely more on procedural memory (13, 14, 24). Additionally, grammar should rely more on declarative memory at earlier than later stages of learning within an individual language learner, since learning in declarative memory takes place more quickly than in procedural memory (13, 14, 24). For these reasons, adult second language learners should initially rely particularly on declarative memory for grammar, although, with increasing L2 experience, they should eventually depend substantially on procedural memory (24). However, grammar in L1 as well as higher experience L2 may also rely to some extent on declarative memory, due to age effects as well as variability in declarative or procedural memory abilities (13, 14, 24). Indeed, even older children may still rely to a fair extent on declarative memory for L1 grammar, since they may still be undergoing proceduralization (13, 14, 24).

The predictions of the DP model can be tested in various ways. A fair amount of research has linked language to the neural correlates of the two learning and memory systems, in both neurological and neuroimaging studies (13, 14, 24), although interpretation of the evidence has been debated (29–31). An increasing body of work has also examined associations between language measures and behavioral measures of learning abilities in the two systems. Such an approach may be a particularly valid test of the predictions of the DP model, since declarative and procedural memory may be best operationalized as the learning and memory abilities that depend on particular neural circuitry: medial temporal lobe and associated structures for declarative memory, and basal ganglia and associated structures for procedural memory (25, 26). This avoids the problems of purely behavioral operationalizations, which often conflate explicit/implicit knowledge and the declarative/procedural systems [the declarative memory system seems to underlie implicit as well as explicit knowledge, and procedural memory is one among several systems to underlie implicit knowledge (14, 25, 32)]. Purely neural operationalizations are also problematic, since the neural substrates of both systems may additionally underlie nonlearning functions (14, 33–35), so linking language solely to the systems’ neural correlates may not reliably implicate declarative or procedural memory. For example, the role of the basal ganglia in grammar may in part be due to its roles in attention and working memory as well as its role in procedural memory (14, 35, 36). Indeed, associations between behavioral measures are not susceptible to certain confounds found in neurological or neuroimaging studies. In neuroimaging studies, two functions can lead to activation of the same regions even if they depend on distinct neural correlates at a more fine-grained level (37). Similarly, in disorders two functions may be similarly affected not only because they share the same neural substrates but also because their distinct neural correlates are anatomically proximate. Thus,

overall, a powerful empirical approach for testing the DP model is to examine the predicted pattern of correlations between measures of particular language abilities and measures of learning abilities in one or the other system.

Although an increasing number of such correlational studies have been published (38–54), it has been difficult to ascertain the pattern across them, given important differences among the studies. The studies have varied regarding which aspects of language (lexicon or grammar) and which memory system (declarative or procedural) they have focused on, whether they have probed L1 or L2, and the amount of second language experience in L2, as well as factors such as the nature of the tasks (e.g., testing receptive or expressive language), what aspect of grammar they target (syntax, morphosyntax, or regular inflectional morphology), which language they focus on (English, French, Spanish, Finnish, or Japanese), and the number of participants. One solution to reveal underlying patterns across these studies is to test each specific predicted association with a separate quantitative metaanalysis (e.g., regarding links between grammatical abilities and procedural memory in adult second language learners with higher levels of L2 experience). Such a hypothesis-driven metaanalytic approach provides a rigorous synthesis of the available evidence for each association, with the potential to reveal consistencies across studies that employ different tasks and measures, or that focus on different aspects of grammar or different languages. Such a metaanalytic approach is more likely to generate valid and generalizable findings than individual studies.

Thus, we conducted multiple metaanalyses to assess multiple predictions of the DP model, in both first and second language. We focused on typically developing individuals, since the core question of domain specificity/generalizability regards typical language learning, which indeed is the subject of the DP model’s core predictions. The only correlations that met our inclusion criteria (*Methods*) were from studies of child L1 or adult L2 (i.e., no relevant correlations were from adult L1 or child L2). Each metaanalysis thus examined results from correlations between behavioral measures of lexical or grammatical abilities and behavioral measures of declarative or procedural learning abilities, either in child L1 or adult L2. For L2, we performed separate metaanalyses at lower and higher levels of language experience, given that the DP model makes different predictions for the two. The metaanalyses were performed over a total of 56 correlations (40 after weighted averaging) and 665 individuals (*Methods*). For a list of the studies and their key characteristics, see [Tables S1](#) and [S2](#). Based on the DP model, we predicted positive correlations between lexical abilities and learning abilities in declarative but not procedural memory. In child first language, grammatical abilities were predicted to correlate mainly with procedural memory. In adult second language, grammar was predicted to be linked to declarative memory at lower L2 experience, but mainly to procedural memory at higher experience.

Results

Metaanalyses of correlations in children (aged about 5–10) between first language abilities and learning in the two memory systems (Figs. 1 and 2) revealed, first of all, that lexical abilities were significantly related to learning in declarative memory (mean weighted $r = 0.409$, $P < 0.001$), with a large effect size (55) (Fig. 1A), but not to learning in procedural memory (mean weighted $r = 0.086$, $P = 0.166$), with a small effect size (Fig. 1B). In contrast, grammar abilities were linked to procedural learning (mean weighted $r = 0.269$, $P = 0.043$), with a medium effect size (Fig. 1C), as well as to declarative learning (mean weighted $r = 0.160$, $P = 0.024$), although with a small effect size (Fig. 1D).

No correlational studies between second language lexical abilities and learning in the two systems were found in our literature search, so our metaanalyses examined only correlations

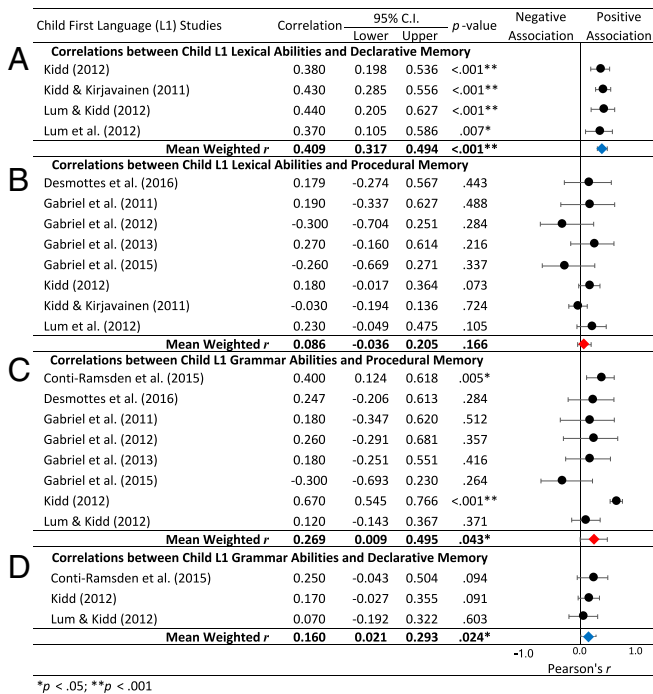


Fig. 1. (A–D) Forest plots for metaanalyses of correlations between child first language (lexical or grammatical) abilities and learning abilities (in declarative or procedural memory). The Forest plot for each of the four metaanalyses shows individual study correlation coefficients entered into the metaanalysis, together with the mean weighted correlation coefficient for the metaanalysis. C.I., confidence interval.

with second language grammar. Participants in all studies were about 20–30 y old. Correlations were categorized a priori (before metaanalysis) as examining language at lower or higher L2 experience (*Methods*).

Metaanalyses of correlations between adult second language grammar abilities at lower L2 experience and learning in the two systems (Figs. 2 and 3) revealed a significant relation between grammar and declarative learning (mean weighted $r = 0.455$, $P = 0.002$), with a large effect size (Fig. 3A), but not between grammar and procedural learning (mean weighted $r = -0.099$, $P = 0.525$), with a small effect size (Fig. 3B). In contrast, metaanalyses of correlations with second language at higher L2 experience revealed a significant correlation between grammar and procedural learning (mean weighted $r = 0.548$, $P < 0.001$), with a large effect size (Fig. 3C), but not between grammar and declarative learning (mean weighted $r = -0.069$, $P = 0.716$), with a small effect size (Fig. 3D).

Discussion

In summary, in child first language, lexical abilities correlated significantly with learning abilities in declarative memory, with a large effect size, but did not correlate with learning in procedural memory. Grammatical abilities showed a more complex pattern. In child first language, grammar correlated with procedural memory, although with a small effect size, as well as with declarative memory, although with a small effect size. In adult second language, at lower L2 experience grammar correlated with declarative memory, with a large effect size, but not with procedural memory, whereas at higher L2 experience grammar correlated with procedural memory, again with a large effect size, but not with declarative memory.

What might explain this pattern? First of all, the observed correlations might be explained by one or more other processes tapped by both the language and learning tasks. For example, because no tasks are process-pure, perhaps the involvement of

working memory or another function in both types of tasks could account for the pattern. However, it is not clear how shared variance in working memory, or indeed any other factor we are aware of, could explain (let alone predict) the particular pattern of correlations observed between specific language and learning abilities in child L1 and in adult L2 at lower and higher experience. It might also be argued that the correlations reflect a dependence of learning abilities on language rather than the converse, particularly if the learning tasks were verbal. However, all procedural memory tasks were nonverbal, and, although most of the declarative memory tasks were verbal, the same correlation patterns were found for nonverbal as for verbal declarative memory tasks [the two studies that reported separate correlations between nonverbal declarative memory tasks and language both found positive correlations, with medium and large effect sizes (49, 52), in line with the other individual study correlations in the respective metaanalyses, as shown in Figs. 1A and 3A]. Note that although a correlational approach is in principle susceptible to confounding factors (including arguably correlational methods such as fMRI and event-related potentials, as well as causal methods such as transcranial magnetic stimulation, transcranial direct current stimulation, pharmacological manipulations, and the lesion method), the highly predictive approach taken here greatly minimizes likely alternative accounts. Indeed, we know of no alternative account that predicts the pattern of correlations observed here between language and learning abilities in child L1 and adult L2 at both lower and higher L2 experience.

In contrast, the pattern of results is fully consistent with the predictions of the declarative/procedural model, and thus with the fundamental claim that language relies on the two learning systems. Indeed, the findings strengthen the model and its claims. First of all, the observed pattern of correlations between the language and learning measures closely matched the full pattern of predictions. Not only did all correlations that were strongly predicted yield large (Figs. 1A and 3A and C) or

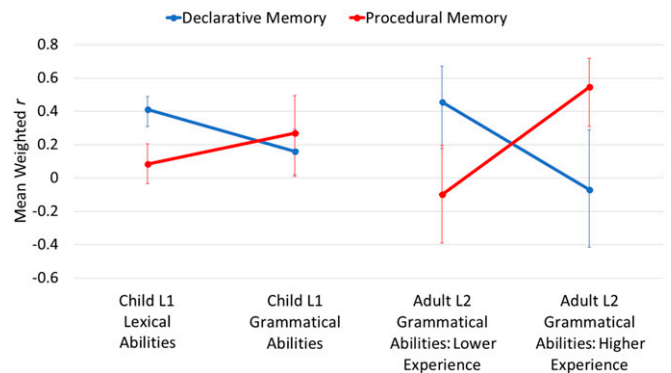
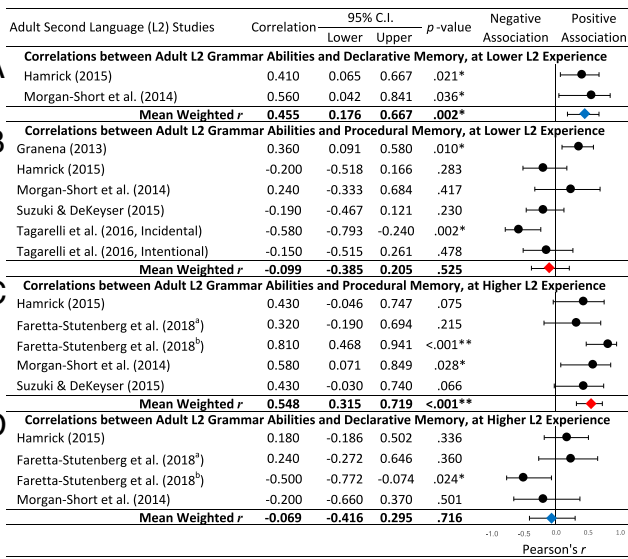


Fig. 2. Graph showing relationships between the mean weighted correlation coefficients (mean weighted r) of contrasting child L1 metaanalyses (*Left*) and of contrasting adult L2 metaanalyses (*Right*). Error bars represent 95% confidence intervals. For child L1 metaanalyses, the mean weighted r value for the correlation between lexical abilities and declarative learning was significantly ($P < 0.05$) larger than the mean weighted r for the correlation between lexical abilities and procedural learning [two means are significantly different if their 95% confidence intervals do not overlap or if both of their confidence intervals extend less than one-half the length of the other's (56)]. In contrast, the correlation between grammar and procedural learning did not differ significantly from the correlation between grammar and declarative learning. For adult L2 metaanalyses, at lower L2 experience, the mean weighted r for the correlation between grammatical abilities and learning in declarative memory was significantly (56) ($P < 0.05$) larger than the mean weighted r for the correlation between grammatical abilities and procedural learning. In contrast, at higher L2 experience, grammatical abilities correlated more strongly with procedural learning than with declarative learning.



*p < .05; **p < .001

Fig. 3. (A–D) Forest plots for metaanalyses of correlations between adult second language grammatical abilities (at lower or higher L2 experience) and learning abilities (in declarative or procedural memory). The forest plot for each of the four metaanalyses shows individual study correlation coefficients entered into the metaanalysis, together with the mean weighted correlation coefficient for the metaanalysis. C.I., confidence interval. ^aForeign language learning (at home) context. ^bSecond language learning (study abroad) context.

medium (Fig. 1C) effect sizes, but additionally, all those that were expected to be absent, weaker, or more variable yielded small effect sizes (Figs. 1B and D and 3B and D). Emphasizing this contrast, the correlations for the former were generally significantly larger than the latter (Fig. 2).

The fact that the patterns were found in metaanalyses underscores their validity. Moreover, the patterns were highly reliable. In particular, in the metaanalyses whose correlations were strongly predicted (Figs. 1A and C and 3A and C), the vast majority (18 of 19) of the individual study correlations showed the same pattern, in that all 18 were positive, and moreover within their respective metaanalyses they either did not differ from each other [given the degree of overlap in their confidence intervals (56)] or were larger than one or more of the others.

Indeed, this reliability was found despite the fact that these 18 individual study correlations varied substantially in a number of dimensions (to different extents across the metaanalyses). The 18 correlations were observed across different languages and language families [French (40, 42–44), Spanish (41), English (38, 46, 48, 49), Finnish (47), and Japanese (53)] as well as in two distinct artificial languages (51, 52); in tasks probing different aspects of grammar, including syntax (38, 40, 41, 43, 44, 46, 49, 51–53), morphosyntax (40, 42–44, 48, 49, 53), and regular inflectional morphology (48); across expressive (40, 42–44, 46, 48, 49) and receptive (38, 40–44, 46–49, 51–53) language tasks probing both lexical (46–49) and grammatical (38, 40–44, 46, 48, 51–53) abilities; in both auditory (38, 40, 42–44, 46–49, 52, 53) and visual (41, 51) modalities in receptive language; in different L2 learning contexts (41, 51–53); and across various measures of both declarative memory [paired associates (38, 41, 46–49, 51, 52), paragraph recall (38, 49), and visual memory (49, 52)] and procedural memory [sequence learning (38, 40–44, 46–51, 53, 54), probabilistic classification (41, 52), and cognitive skill acquisition (52)]. Thus, it is not the case that only certain aspects of language (e.g., inflectional morphology) depend on the learning systems. Rather, converging with results from previous research

using other approaches (including causal approaches such as the lesion method) (13, 14, 24, 57), the findings indicate that language shows a broad and robust reliance on declarative and procedural memory, strengthening the validity of the model. Note that the generality of the patterns also further reduces the likelihood that confounding variables might explain the associations, since such variables may be specific to particular conditions—for example, to receptive language, one aspect of grammar, or one type of learning task.

The observed pattern of correlations not only strengthens clearly predicted aspects of the model but also further elucidates certain previously unclear language/learning system relations, allowing the nature of these relations (and thus the model) to be further specified. Perhaps most importantly, the extent to which grammar should rely on declarative memory has been difficult to predict in certain circumstances, in particular in child L1 and in adult L2 at higher experience (13, 14, 24) (see above). The findings presented here suggest that child L1 grammar does indeed depend to some extent on declarative memory, at least between about 5 and 10 y of age (38, 46, 48). In fact, this reliance seems to be quite consistent, since the three study correlations did not differ significantly from one another (given their confidence interval overlap; Fig. 1D). Future studies should clarify whether the reliance of L1 grammar on declarative as well as procedural memory differs as a function of age, individual variability, or other factors (13, 14, 57).

In contrast, the results suggest that at higher L2 experience adult learners do not depend reliably on declarative memory for grammar. Variability in the individual study correlations (Fig. 3D) in fact suggests variability in this dependence, which could be due to a range of factors (e.g., variability in L2 learning contexts, individual abilities, aspects of grammar tested). Interestingly, the mean weighted correlation was negative, and one of the contributing studies was significantly negative (41) (Fig. 3D), suggesting the possibility that at least in some cases better learning abilities in declarative memory are associated with worse grammar. This is consistent with the “seesaw effect” hypothesized by the declarative/procedural model, in particular that learning in one system can impede learning or processing in the other (13, 14, 24, 58). Moreover, the same pattern was observed for the association between procedural memory and grammar at lower L2 experience (54) (Fig. 3B), underscoring the possibility that the seesaw effect may indeed play a role in adult L2 grammar learning.

Overall, the findings demonstrate that language indeed relies on general-purpose cognitive systems, moreover in systematic ways that are consistent with biological and evolutionary principles. Domain generality does not, however, preclude the concomitant existence of domain-specific substrates for language, either due to ontogenetic (developmental) or phylogenetic (evolutionary) specialization within these systems, or to additional specialized circuitry (1, 5, 7, 9, 13, 37, 59)—although the actual demonstration of domain specificity remains challenging (3, 4, 12). Nor does it preclude other forms of domain generality in language, some of which may complement or extend the domain generality shown here (2, 13, 14, 60, 61). Indeed, where other claims of domain generality can generate a specific set of predictions, the approach employed in the present study may prove useful.

Furthermore, by providing comprehensive evidence supporting (and further specifying) the declarative/procedural model regarding its fundamental claims about the dependence of language on the two learning systems, this study lays a solid foundation for future research. Extensive animal and human studies have led to an increasingly broad and deep understanding of the two systems, including their genetic, cellular, electrophysiological, neuroanatomical, learning, developmental, and evolutionary bases (13, 14, 25–28, 32, 62). Demonstrating that language relies on these systems suggests that our substantial knowledge of the systems may

also apply to this domain. Thus, the present study may spur the investigation of a wide range of specific and often unique predictions that there might be no reason to make in the more limited study of language alone. For example, this approach can identify candidate genes (e.g., *BDNF*, *PPPIR1B*) (14) for language, whose genetic basis is still largely unknown. Similarly, the evolution of language may be elucidated by examining the evolution of the biological mechanisms of the systems (63). More generally, linking language to the learning systems has the potential for high impact, since it suggests the possibility of animal models for aspects of language; as imperfect as such models are, they have contributed substantially to our understanding of other aspects of (neuro)biology (26, 63, 64), and thus have the potential to do so for language as well (13, 14). Note that the fact that the systems subserving learning has particular implications for language acquisition (13, 14, 24). The predictions also extend to translational research (13, 14, 62, 65). Of both clinical and educational relevance, a variety of behavioral, pharmacological, and other methods have been found to improve the learning or use of knowledge in the systems (62, 65), suggesting that such approaches could also be employed in language disorders (e.g., aphasia, specific language impairment, dyslexia, autism) as well as for second language learners (62, 65).

The study has also revealed gaps in previous research that would be useful to address in future studies. The literature search indicated that some language/learning system links have been examined less than others, such as between L2 lexical abilities and declarative memory, between grammar and declarative memory at lower L2 experience, and between both language abilities and both learning systems in both adult L1 and child L2. The influence of certain moderating variables on language/learning system links, such as the degree and type of L2 experience, and subject-level variables such as sex or handedness, could also benefit from additional research (13, 14, 24). Similarly, further research should examine language/learning system associations in disorders, which may show different patterns than typically developing populations (13, 62, 66). Note that certain apparent gaps regarding language/learning systems links have in fact been examined to some extent, although the relevant correlations were not included in our metaanalyses due to the selection criteria (*Methods*). Quite a few of these correlations were in fact significant, across various language and learning measures (67–70) and populations, including infants and toddlers (70, 71) and children with various disorders (49, 72), further strengthening the hypothesis that language depends importantly on these general-purpose systems.

In sum, this study provides comprehensive evidence linking language to both declarative and procedural memory in both first and second language. The results demonstrate that both lexical and grammatical abilities depend in systematic ways on general-purpose learning systems. Thus, the evidence suggests that core aspects of language do in fact rely importantly on general-purpose mechanisms that preexist this uniquely human capacity.

Methods

A systematic search for articles in Medline, PsycInfo, ERIC, EbscoHost, Linguistics and Language Behavior Abstracts, and ProQuest, together with a list of

potentially relevant articles known to the researchers, yielded 15,225 papers as of April 2016. These papers comprised only investigations that reported on an original piece of research that had been published or had been accepted for publication, as well as master's theses and doctoral dissertations (all of these types of publications are contained in the databases). There were no restrictions on publication date. For details of the syntax used for the database searches, and the fields searched, see Fig. S1. The full search, screening, and selection process is summarized in the PRISMA flowchart (73) shown in Fig. S2. For further details on the methods, see *SI Methods (Abstract Screening, Study Inclusion Criteria, and Data Extraction and Coding)*.

After removing 12,112 duplicate papers (records) from the initial set of 15,225, we performed an "abstract screening" step to determine whether each of the remaining 3,113 papers was likely to contain the required data (Fig. S2). Specifically, if there were any indications from the title, abstract, or keywords that the study might report at least one behavioral measure of lexicon or grammar and at least one behavioral measure of learning in declarative or procedural memory, the study was retained; otherwise, it was removed. Despite this conservative approach, in which we retained all studies that might contain the relevant information in order to minimize unwarranted rejections, the majority of papers were found not to be related to the constructs of interest, as revealed by the 3,060 records removed during abstract screening (Fig. S2). See *Abstract Screening in Supporting Information* for more details.

Subsequent to abstract screening, we evaluated the full text of the remaining 53 papers (Fig. S2). This final selection step resulted in the exclusion of 37 papers; these are listed in Table S3, along with the primary factor(s) motivating their exclusion. The remaining 16 papers were included in our metaanalyses. Ten papers examined child L1; these are listed in Table S1, along with their study characteristics. Six papers examined adult L2; these are listed in Table S2, along with their study characteristics. The final selection step was carried out independently by the first and second authors, with 100% agreement between the two on both the excluded and included papers.

The final selection step employed study inclusion criteria that allowed us to test the specific predictions of the declarative/procedural model for first and second language in typically developing individuals. Included papers had to examine, in typical populations, associations between behavioral measures of either lexicon or grammar on the one hand, and behavioral measures of learning in either declarative or procedural memory on the other. Thus, studies that only reported combined measures of lexicon and grammar (e.g., ref. 74), or combined measures of learning in the two systems, were not included—since these would not allow examination of the model's distinct predictions for lexicon and grammar in the two systems. Papers with any appropriate language/learning system correlations in typical populations were potentially included, even if the papers also examined such correlations in atypical populations, which were not of interest. However, if papers only included correlations from atypical populations, or if they reported only correlations that combined typical and atypical populations, they were excluded (39, 49, 72). For example, although one study (39) included an appropriate lexical/declarative learning correlation in child L1, the population examined included both typical and atypical readers, and thus the paper was excluded (Table S3). See *Study Inclusion Criteria in Supporting Information* for more details and examples.

Finally, for each appropriate language/learning system correlation in these papers, we extracted two data points: the correlation coefficient and its associated sample size. Weighted mean correlations based on this information were computed using Comprehensive Meta-Analysis (75). After weighted averaging, the original 56 correlations yielded 40 weighted correlations, over which the metaanalyses were computed, again using Comprehensive Meta-Analysis. See *Data Extraction and Coding in Supporting Information* for more details. Analysis revealed no evidence of publication/selection bias in the final set of papers included in the metaanalyses (Fig. S3).

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