The Role of Prior Knowledge in Morphological Learning in an Artificial Second Language

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Abstract

Morphology plays a critical role in effectively using and understanding a language. Therefore, it is important to identify the factors that contribute to the success with which individuals are able to learn morphological regularities. This study explores the potential role of prior knowledge in learning derivational morphemes in an artificial language. Consistent with the Complementary Learning Systems theory, it is hypothesized that native English-speaking participants will demonstrate faster learning and consolidation for morphological regularities that are consistent with morphological structures in English as opposed to morphological regularities that are infrequent in English.

Learning a second language (L2) can have significant social and occupational advantages (e.g., Mehisto & Marsh, 2011; Rumbaut, 2014). Thus, it is not surprising that many adults attempt to learn an L2 later in life. While some late L2 learners are able to achieve native-like fluency, a considerable amount fail to attain even a high level of proficiency (e.g., Abrahamsson & Hyltenstam, 2009; Birdsong & Molis, 2001; Johnson & Newport, 1989). A large body of work has emerged aimed at identifying the factors that drive these individual differences in L2 learning (see Wen et al., 2017 for a review), with a subset of this research focused specifically on understanding how domain-general cognitive mechanisms support the L2 learning process (e.g., Juffs & Harrington, 2011; Miyake & Friedman, 1998; Morgan-Short et al., 2014). In line with this research, the current study investigates a model of L2 acquisition based on the Complementary Learning Systems (CLS) theory, a domain-general model of learning (McClelland et al., 1995; McClelland, 2013; McClelland et al., 2020).

One of the hallmarks of human language is the ability to flexibly use and assign meaning and function to both known as well as newly learned structures. This flexibility is facilitated by the compositional nature of language. For example, words can be broken down into smaller meaningful parts (i.e., morphemes) that can be combined with other parts to form new words. Depending on their regularity in a language, these morphemes can also be used as a cue to the meaning or functional role of an unknown word. For example, knowing that in English adding the inflectional morpheme -s to “dog” implies more than one dog, or that adding the derivational morpheme un- to “dress” signifies the opposite of putting on clothes, may facilitate an individual’s understanding of less frequent words such as “penguins” or “unequal.” This ability to use prior morphological knowledge to facilitate language comprehension can be used both to understand new or unfamiliar words in one’s native language (L1) as well as in L2 learning contexts. If a morphological regularity (e.g., *add a morpheme to the end of words to signify ‘more than one’*) is present in both a learner’s L1 and the L2 they are trying to learn, the learner may be able to rely on their L1 knowledge to facilitate L2 learning. The CLS theory (McClelland et al., 1995; McClelland, 2013; McClelland et al., 2020) provides a theoretical foundation and potential neurobiological mechanism through which this type of cross-linguistic transfer could occur. The aim of the current study is to investigate whether the learning principles outlined by the CLS theory contribute to L2 morphological learning.

Background Literature

The Complementary Learning Systems (CLS) Theory

According to the CLS theory (McClelland et al., 1995; McClelland, 2013; McClelland et al., 2020), obtaining new knowledge occurs through an interaction between two neurobiological systems. Initially, new knowledge is rapidly encoded within the hippocampal system as detailed and contextualized episodic memories. Over time, regularities are extracted and the relevant knowledge is consolidated into decontextualized semantic memories supported by neocortical structures. To facilitate this consolidation process, information is passed between the hippocampal system and the neocortex via bidirectional pathways. Each new relevant experience or offline replay of a previous relevant experience leads to the reactivation of stored patterns within the hippocampus and thus, via the bidirectional pathways, the neocortex. Each reinstatement within the neocortex produces incremental changes to the connections within neocortical structures. Eventually, these changes accumulate to produce a stable pattern of activation within the neocortex that represents the learned knowledge. At this point, the

knowledge is said to be consolidated and its representation is no longer hippocampally-dependent.

The CLS theory was developed to account for how a system could effectively learn new information that was related to, but at least partially inconsistent with, known information. Under these circumstances, models of learning have shown that the rapid integration of this type of new information into stored knowledge causes strong interference with what is already known. According to the CLS theory, our memory system minimizes the potential for this catastrophic interference by utilizing two complementary learning systems. A fast-learning hippocampal system, which allows new experiences to be encoded and utilized immediately, and a slow-learning neocortical system, which allows for the gradual integration of new knowledge into long-term memory.

Since this original conceptualization, the CLS theory has been adapted to account for new findings from neuroscientific research. Consistent with CLS theory, Tse and colleagues (2007) showed, using rats, that learning new flavor-location pairs was supported by the hippocampus, as lesions to the hippocampus before training resulted in a lack of improvement over the course of training. However, inconsistent with the CLS theory, this reliance on the hippocampus was not found when new learning occurred after a task schema was developed. When rats were given a single trial of two new pairings following extensive training on a set of original pairs, they showed rapid acquisition of the new associations and strong retention of the associations after 24 hours. Critically, hippocampal lesions 48 hours after initial exposure to the new pairs did not result in a loss of the new pairings. In fact, the rats showed strong retention of both the original pairs as well as the two newly learned pairs. When moved to a new environment, sham-lesioned rats were able to learn additional new pairs, but the hippocampal-lesion rats failed to learn new associations in the novel environment. Tse and colleagues (2011) extended this work in a subsequent experiment by showing that the learning of new schema-consistent associations (e.g., the two new pairings presented to the rats after initial training) resulted in the expression of plasticity associated genes in the neocortex.

In light of these findings, the original CLS theory was revised such that rather than characterizing the neocortex as a slow-learning system, it was argued that neocortical learning is prior-knowledge dependent. That is, information that is consistent with existing knowledge is quickly consolidated but information that is novel or inconsistent with existing knowledge is slowly consolidated through the more gradual learning process originally outlined (McClelland, 2013; McClelland et al., 2020). This more complete characterization of the learning process provides a neurobiological mechanism through which prior knowledge may facilitate learning.

Learning and Consolidation of Novel Words

Gaskell and colleagues were the first to extend the CLS theory to the domain of word learning (Davis & Gaskell, 2009; Lindsay & Gaskell, 2010). In line with the CLS theory, it was argued that experiences with novel words are initially encoded within the hippocampal system as distinct episodic memories. Over the course of multiple encounters with the novel words through new experiences, active rehearsal, or offline replay during inactive states such as sleep, long-term representations are formed within the neocortex. This complementary learning systems account of word learning is well-supported by research showing that during word learning activation within the medial temporal lobe (which includes the hippocampus) reduces over the course of repeated exposure to novel words (e.g., Breitenstein et al., 2005; Davis et al., 2009). This account is further supported by the robust evidence for the role of (primarily) left-

hemisphere occipito-temporal and frontal neocortical regions during the processing of known words/sentences (for a review see Friederici, 2011).

Behavioral research has also provided strong support for the CLS theory of word learning (e.g., Bakker et al., 2014; Bowers et al., 2005; Clay et al., 2007; Davis et al., 2009; Dumay & Gaskell, 2007; Gaskell & Dumay, 2003; Tamminen & Gaskell, 2008; Tamminen & Gaskell, 2013; Tamminen et al., 2010; Tham et al., 2015; van der Ven et al., 2015; Wang et al., 2017). Gaskell and Dumay (2003) trained participants on pseudowords (e.g., cathedruke) that were consistent with known words (e.g., cathedral) in their onset but diverged from the known words at that word's uniqueness point. Participants were trained on the novel words through a phoneme monitoring task over the course of five days. Recognition of the novel word's form was tested with a two-alternative forced choice test and interactions between the novel words and preexisting words was tested with a lexical decision task. It was hypothesized, based on the CLS theory of word learning, that interactions between novel words and preexisting words can only occur after the novel words have been consolidated into an individual's mental lexicon. The authors found that performance on the recognition tasks was high throughout training, but evidence of consolidation through a lexical competition effect did not emerge until day four of training. Since this initial experiment, Gaskell and others have demonstrated that these effects are robust across a wide range of additional study designs including single day training paradigms (e.g., Davis et al., 2009; Dumay & Gaskell, 2007; Tamminen et al., 2010), word meaning training paradigms (e.g., Tamminen & Gaskell, 2013; van der Ven et al., 2015), and written word training paradigms (e.g., Bakker et al., 2014; Bowers et al., 2005; Clay et al., 2007; Wang et al., 2017).

There has been less research on the time course of novel morphological learning but the findings have been generally consistent with the broader work on the time course of novel word learning (Ben-Zion et al., 2019; Merkx et al., 2011; Mirkovic et al., 2019; Tamminen et al., 2015; Tamminen et al., 2012). Within the context of morphological learning, the ability to generalize the function of a morphological regularity to new exemplars, particularly in speeded contexts, is taken as evidence of consolidation. While there is evidence that generalization can be facilitated by sparse hippocampal representations (e.g., Kumaran & McClelland, 2012), this process is thought to be much slower than generalization that is supported by distributed representations within the neocortex. Therefore, when generalization is observed under speeded conditions, this is taken as evidence that neocortical consolidation has occurred.

Tamminen and colleagues have provided some of the most compelling evidence in support of a delayed consolidation effect during morphological learning. Participants were trained on novel words consisting of a known stem (e.g., sleep) and an unfamiliar suffix (e.g., -afe). Each novel word was associated with a definition that was related to the meaning of the known stem (e.g., sleepafe = a participant in a study about the effect of sleep). Following training, Tamminen and colleagues tested participants' ability to generalize the suffix meanings in both a speeded and non-speeded condition. Their results across five experiments revealed that participants were able to generalize under non-speeded conditions across a wide variety of training contexts in which the time between training and testing, the number of unique stems the suffix was paired with, and the consistency of the suffix meaning were all systematically varied. However, under speeded conditions, evidence of generalization was only observed when there was an opportunity for consolidation between training and testing, when there was a sufficient number of unique exemplars, and when there was consistency in the suffix meaning (or there was a period of consolidation between learning two different meanings of a suffix; Tamminen et

al., 2015). This pattern of results is directly in line with what would be predicted by the broader CLS theory (McClelland et al., 1995; McClelland, 2013; McClelland et al., 2020) and the more specific CLS theory of word learning (Davis & Gaskell, 2009; Lindsay & Gaskell, 2010). That is, generalization under speeded conditions only occurs after consolidation and if there is a sufficient number of consistent exemplars to allow for the extraction of the regularity.

The Role of Prior Knowledge in Novel Word Learning

According to the CLS theory (McClelland et al., 1995; McClelland, 2013; McClelland et al., 2020), the time between initial acquisition and long-term consolidation is facilitated by similarity between the to-be-learned information and prior knowledge. Within the context of word learning, prior knowledge may manifest in multiple ways. At the highest level, prior knowledge may take the form of general linguistic or meta-linguistic knowledge. Support for the role of this type of prior knowledge comes from research showing that individual differences in phonological awareness, vocabulary, and reading skill are predictive of both general word learning success and, more specifically, the time course of novel word consolidation (e.g., Ben-Zion et al., 2019; Bitan & Booth, 2012; James et al., 2019; Landi et al., 2018).

At a lower level, and particularly within the context of L2 word learning, prior knowledge may take the form of shared linguistic features or linguistic forms. One way in which shared linguistic features are represented across languages is through common grammatical rules. Cross-linguistically these rules may be marked in different ways (i.e., grammatical gender marked with affixes vs. determiners), yet the shared grammatical rule stills facilitate an individual's ability to learn the rule in the L2 context. Psycholinguistic research on cross-linguistic transfer has shown support for the role of this type of prior knowledge. That is, research investigating L2 learning has shown that individuals are better able to learn L2 features that are also present in their L1 (e.g., Luk & Shirai, 2009; Sabourin et al., 2006).

At the lowest level, prior knowledge may manifest through shared linguistic forms. While the role of this type of prior knowledge has not been investigated within the context of morphological learning, studies have explored the role of shared phonological forms in L2 word learning (Havas et al., 2018; Nora et al., 2012; Nora et al., 2015). These studies have overall demonstrated better learning for novel words composed of L1-similar phonological forms as compared to L1-dissimilar phonological forms. However, they have either not explored (Nora et al., 2012; Nora et al., 2015) or failed to find evidence (Havas et al., 2018) that this type of L1-L2 similarity facilitates the consolidation process. Havas et al. (2018) found that native Spanish speakers learning novel words that were either phonologically similar to Spanish or to an unfamiliar language (Hungarian) were more successful at acquiring the novel words consistent with their L1. Twelve hours after training, Havas and colleagues (2018) used a primed lexical decision task to test for the consolidation of the newly learned words. In this task, the newly learned words were presented as auditory primes, followed by visually presented target words that were either the Spanish translation equivalent to the prime, a Spanish word unrelated to the prime, or a Spanish non-word. It was hypothesized that following consolidation the newly learned words should be able to prime existing words. Havas et al. (2018) failed to find evidence of priming for either the L1-similar or L1-dissimilar words. While the results of this study are inconsistent with the hypothesis that similarity between L1 and L2 linguistic forms will facilitates consolidation, the lack of evidence for consolidation 12 hours after training is in line with prior work demonstrating that it can take several days or weeks for newly learned words to show evidence of consolidation (e.g., Gaskell & Dumay, 2003; Merkx et al., 2011).

The Present Study

The aim of the current study is to extend previous research by using a multi-day artificial language training paradigm to explore whether the learning principles outlined by the CLS theory contribute to L2 morphological learning. In particular, the present study will investigate how success learning derivational morphemes varies based on L1-L2 similarity at the level of linguistic forms. In line with the CLS theory (McClelland et al., 1995; McClelland, 2013; McClelland et al., 2020), it is predicted that participants will more rapidly consolidate morphological structures that are present in English and therefore will show improved learning for these structures.

Methods

Participants

Simulation-based power analyses were conducted using *simr* (number of simulations = 1000; $\alpha = 0.05$; Green & MacLeod, 2016) in R (R Core Team, 2019) to determine the necessary sample size to detect condition differences with at least 80% power. A common model was used across the four outcome variables (Overall Learning, Learning Rate, Consolidation, and Generalization; to be described subsequently) which included fixed effects associated with the three task conditions (L1-similar, L1-dissimilar, and Simple; to be described subsequently) and a random intercept component. Estimates for the fixed and random effects were generated separately for each outcome variable based on data from eight pilot participants. With a sample size of 45, the power analyses indicated very high power to detect differences between the L1-similar and Simple conditions (range of 95% confidence intervals around the power estimates across outcome variables: 99 to 100%) and moderate to high power to detect differences between the L1-similar and L1-dissimilar conditions (range of 95% confidence intervals around the power estimates across outcome variables: 81 to 100%). Thus, 45 adults (ages ranging from 18 to 35 years) will be recruited to participate in this study to ensure adequate power to detect differences in learning across the four outcome variables.

All participants included in the study will be right-handed, native English speakers, with no neurological diseases, or learning or intellectual disabilities. In addition, all participants will have some exposure to an L2 through a classroom setting. However, no participants will report being exposed to a non-English language in the home, having spent more than 6 months studying or living in a non-English speaking country, or being proficient in an L2 (as measured by self-reported proficiency ratings of greater than 4 on 0-to-10 point speaking and understanding proficiency scales from the Language Experience and Proficiency Questionnaire; Marian et al., 2007).

Procedures

All study procedures have been approved by an Institutional Review Board and informed consent will be obtained from all individuals prior to participation. Participants will complete five experimental sessions over the course of 2-3 weeks. During the first session, participants will complete demographic surveys and a series of behavioral tasks. During all other sessions, participants will be trained and tested on novel words in an artificial language. At the end of their final session, participants will complete a post-training questionnaire on their knowledge of the morphological structures within the artificial language.

Behavioral Tasks

Working Memory. It is well established that working memory is a strong predictor of individual differences in language learning (e.g., Miyake & Friedman, 1998). Therefore, working memory will be included as a covariate in all analyses. Variability in working memory capacity will be measured using the Operation Span and Rotation Span tasks (Foster et al., 2015). In both tasks, participants are instructed to remember of sequence of items. In between the presentation of each item, participants are required to complete a distractor task. After all items have been presented, participants are asked to recall, in order, the sequence of items. In the Operation Span task, participants alternate between evaluating arithmetic expressions (distractor task) and memorizing individual letters (to-be-remembered item). In the Rotation Span task, participants alternate between evaluating the orientation of a rotated letter (distractor task) and memorizing the direction of individual arrows (to-be-remembered item). Participants will complete two blocks of the Operation Span task (Cronbach's $\alpha = 0.82$) and two blocks of the Rotation Span task (Cronbach's $\alpha = 0.81$). Individual differences in working memory will be indexed through a composite score created by combining partial scores from the two measures.

Morphological Awareness. It is predicted that individual differences in morphological awareness will contribute to variability in the success with which participants learn the artificial L2 morphology. Therefore, morphological awareness will be included as a covariate in all analyses. Morphological awareness will be indexed through three tasks that focus on English derivational morphology: (1) Derived Form Morphology Task (Cronbach's $\alpha = 0.90$), (2) Derivational Suffix Choice Test of Pseudowords (Cronbach's $\alpha = 0.85$), and (3) Morphological Analogy Task with Pseudowords (Cronbach's $\alpha = 0.88$; Tighe & Schatschneider, 2015; Tighe & Schatschneider, 2016a; Tighe & Schatschneider, 2016b). In the Derived Form Morphology Task, participants are presented with a root word and a sentence containing a blank and are asked to fill in the blank with the appropriately derived form of the root word (e.g., Happy. Money does not buy ____; "happiness"). In the Derivational Suffix Choice Test of Pseudowords, participants are instructed to select the appropriate pseudoword from four options (e.g., lorialize, lorial, lorialism, and lorify) that completes a given sentence (e.g., The meeting was very ____; "lorial"). In the Morphological Analogy Task with Pseudowords, participants are presented with a pair of real words (e.g., fuzz : fuzzy) and then a single pseudoword (e.g., squilt) and asked to provide the corresponding pseudoword (e.g., "squilty"). Individual differences in morphological awareness will be indexed through a composite score created by combining the number of correct trials across the three measures.

Language Training

Stimuli. The artificial language to be used in the current study was designed such that words occur in one of three conditions: (1) an L1-similar morphologically complex condition (L1-similar), (2) an L1-dissimilar morphologically complex condition (L1-dissimilar), and (3) a morphologically simple condition (Simple; see Table 1). All morphologically complex words in the artificial language can be decomposed into a root and suffix/pattern. English morphology is largely characterized by the linear combination of a continuous root with a prefix or suffix. Consistent with this concatenative morphological structure, words in the L1-similar condition are composed of a novel continuous root (e.g., fald-) and a novel suffix (e.g., -apa). Alternatively, words in the L1-dissimilar condition are composed of a novel discontinuous root (e.g., g-l-b-k) and a novel discontinuous vowel pattern (e.g., -i---o-) which is interleaved with the root to form the word (e.g., gilbok). This discontinuous morphological structure, while not widely used in

English, is characteristic of some language families, such as Semitic (e.g., Hebrew). Each unique root, across both the L1-similar and L1-dissimilar conditions, corresponds to a specific to-be-learned semantic concept (e.g., fald- = car and g-l-b-k = fish). Similarly, each unique suffix/pattern corresponds to a specific to-be-learned semantic category (e.g., -apa = place and -i--o- = thing). Therefore, each novel word is associated with a to-be-learned meaning that is a combination of the root and suffix/pattern meaning [e.g., faldapa = mechanic shop (a *place* where they fix *cars*) and gilbok = fish tank (*something fish* are kept in)]. This linguistic structure, in which the root of a word represents the semantic concept and the suffix/pattern represents the semantic category, can be observed across a wide array of natural languages [e.g., English: kindness = being kind and kind-ly = in a kind manner vs. loud-ness = being loud and loud-ly = in a loud manner; German: freund-schaft = group of friends (friendship) and freund-lich = friendly vs. mann-schaft = group of men (team or crew) and mann-lich = manly; Hebrew: tigel = to exercise and targil = an exercise vs. tidrekh = to brief and tadrikh = a brief (a statement); Arabic: talaba = to learn (to ask) and tālib = learner (student) vs. kataba = to write and kātib = writer]. Words in the Simple condition are also associated with specific to-be-learned semantic concepts and categories. However, the novel words in the Simple condition consist of non-decomposable words (e.g., valtebi) and words belonging to the same semantic concept or category are not consistent in their phonological or morphological structure [e.g., valtebi = pilot (*somebody* who flies a *plane*) vs. piftona = airport (a *place* where *planes* land)]. This use of a variety of morphological strategies to show semantic contrasts in the artificial language is characteristics of many natural languages [e.g., English: teach – teacher and sleep – sleeper = agentive pairs using a concatenative morphological structure vs. cook – chef and fly – pilot = agentive pairs using a simple, unrelated morphological structure; Maltese: berritta (cap) – berrittin (little cap) and biskott (biscuit) – biskuttin (little biscuit) = diminutives using a concatenative morphological structure vs. tifel (boy) – tfajjel (little boy) and togba (hole) – tgajba (little hole) = diminutives using a discontinuous morphological structure].

In total, thirty-six words were created for each condition, twenty-four of which will be presented during training and twelve of which will serve as untrained words to test generalization during the final session. Half of the words in each condition were created such that they were six letters in length with a CVCCVC structure and two syllables; the other half of the words were created such that they were seven letters in length with a CVCCVCV structure and three syllables. All words were created using the following inventory of consonants and vowels: b, p, d, t, k, g, m, n, l, š, f, v, s, z, a, e, i, o, and u. Voiced oral stops were never used as the final consonant in the L1-dissimilar condition in order to avoid accidental devoicing in the words when the last consonant of the root is also the last consonant of the word. This manipulation was not necessary in the L1-similar condition due to the nature of the suffix.

A female speaker using an English accent recorded all words. During preprocessing, PRAAT (Boersma & Weenink, 2018) was used to trim the auditory recordings around each word and to scale the intensity of each word to 76 dB. WSOLA (program written by Yizhar Lavner from Tel-Hai College) was used to make duration adjustments using a time compression algorithm. Following preprocessing, the average duration for all words was 937ms (Range: 740 – 1126ms). Pairwise *t*-tests were conducted to ensure that there were no significant duration differences between conditions (e.g., L1-similar vs. L1-dissimilar; L1-similar vs. Simple; L1-dissimilar vs. Simple) by syllable length for trained and untrained words separately (Trained - Duration: $p_s > 0.416$; Untrained - Duration: $p_s > 0.309$).

Three sets of 36 (24 trained and 12 untrained) English translations and corresponding English definitions were created for the artificial language (see Table 1). Across the three sets (i.e., Set 1 vs. Set 2, Set 1 vs. Set 3, and Set 2 vs. Set 3), all translations were matched in total number of words, total number of syllables, total number of morphemes, and average word frequency for the trained and untrained words separately (Trained - Words: $ps > 0.701$; Trained - Syllables: $ps > 0.109$; Trained - Morphemes: $ps > 0.162$; Trained - Frequency: $ps > 0.956$; Untrained - Words: $ps > 0.481$; Untrained - Syllables: $ps > 0.157$; Untrained - Morphemes: $ps > 0.501$; Untrained - Frequency: $ps > 0.955$). In addition, to reduce the transparency between the word forms and semantic concepts during training, 50% of the word pairs presented for a given semantic concept explicitly included the semantic concept in both of the translations and 50% of the word pairs for a given semantic concept explicitly included the semantic concept in only one or neither of the translations (e.g., gilbok = fish tank and golbeku = fish market vs. faldapa = mechanic shop and faldine = car driver). All definitions consisted of 3-9 words (average = 5.06 words) and were structured to explicitly include both the semantic concept and category in the definition (e.g., faldapa = a place where they fix cars, faldine = somebody who drives a car, faldom = a lot of cars, and falduk = something a car rolls on). The pairing between the translation/definition sets and conditions will be counterbalanced across participants.

Table 1. Example stimuli in the artificial language by condition.

	Novel Word (Root / Suffix/Pattern)	Semantic Concept (Root Meaning)	Semantic Category (Suffix/Pattern Meaning)	English Translation	English Definition
L1-similar Condition	Faldine (fald- / -ine)	Car	Person	Car driver	Somebody who drives a car
	Faldapa (fald- / -apa)	Car	Place	Mechanic shop	A place where they fix cars
	Falduk (fald- / -uk)	Car	Thing	Car tire	Something a car rolls on
	Faldom (fald- / -om)	Car	A Lot	Traffic jam	A lot of cars
L1-dissimilar Condition	Gulbaki (g-l-b-k / -u---a-i)	Fish	Person	Fisherman	Somebody who fishes
	Golbeku (g-l-b-k / -o---e-u)	Fish	Place	Fish market	A place where you buy fish
	Gilbok (g-l-b-k / -i---o-)	Fish	Thing	Fish tank	Something fish are kept in
	Gelbik (g-l-b-k / -e---i-)	Fish	A Lot	School of fish	A lot of fish

Simple Condition	Valtebi	Plane	Person	Pilot	Somebody who flies a plane
	Piftona	Plane	Place	Airport	A place where planes land
	Zafmate	Plane	Thing	Aircraft carrier	Something that carries planes on the sea
	Sasten	Plane	A Lot	Squadron of planes	A lot of planes

Training Paradigm. Participants will complete four sessions of language training. All four training sessions will consist of three primary phases: (1) pre-test, (2) three blocks of training, and (3) post-test. Each trained novel word (e.g., faldapa) will be presented once during the pre-test, each block of training, and the post-test. Therefore, each phase will consist of 72 trials (i.e., 3 conditions, with 24 words per condition). During all three phases, a trial will consist of the auditory presentation of a novel word followed by the visual presentation of four English translation alternatives. Participants are instructed to orally repeat the novel word and then select the correct English translation (Translation task). During the Translation task, each novel word (e.g., faldapa) will be presented with the correct translation (e.g., mechanic shop), an incorrect-related translation that either corresponds to a novel word with the same root (e.g., car driver which corresponds to faldine; 50% of trials) or suffix/pattern (e.g., banana plantation which corresponds to monsapa; 50% of trials) as the novel word in question, and two incorrect-unrelated translations that correspond to novel words that are unrelated in root or suffix/pattern to both the novel word in question and the incorrect-related translation (e.g., fisherman which corresponds to gulbaki and pilot which corresponds to valtebi). The two incorrect-unrelated translations within a trial share a suffix/pattern meaning on 50% of the trials (the two translations never share a root meaning as they are always from different conditions). Each translation appears once as a correct translation and three times as an incorrect translation during the Translation task. The location of the four alternatives within a 2x2-quadrant space is randomly selected for each trial. The only difference between the structure of the training blocks and that of the pre- and post-tests is that during training participants will receive feedback about the correct translation after a selection is made.

In addition to the three primary phases, the first training session will also include a familiarization phase, which will occur before the first pre-test. During the familiarization phase, participants are auditorily presented with each novel word, asked to orally repeat the word, and then are visually presented with the word's English translation and definition. All novel words (e.g., faldapa) will appear once during the familiarization phase. The last training session will also include an additional familiarization phase and post-test, which will both occur after the three primary phases. The additional familiarization phase and post-test will be composed exclusively of untrained novel words. This final post-test for untrained words will be used to test participant's ability to generalize their knowledge about the artificial language following training.

Across all phases of the training paradigm, participants will be presented with the novel words blocked by condition, with the condition order randomized across participants. Within a condition each novel word will be presented in a randomized order across phases and participants. This training paradigm represents a hybrid-learning environment with aspect similar to classroom-based L2 learning, such as the structured nature of the training, and aspects similar to immersion-based L2 learning, such as the implicit learning required to identify the morphological regularities.

As part of a functional magnetic resonance imaging (fMRI) portion of the study not described herein, participants will also complete additional blocks of testing in an MRI scanner at the end of their first and last training session. During these testing blocks, participants will be auditorily presented with each novel word and then asked to either orally repeat each word or judge the correctness of a subsequently presented English translation. The first fMRI session will include three blocks of testing, during which each trained novel word will be presented once per block. The last fMRI session will include five blocks of testing. During the first three blocks, each trained novel word will be presented once per block. During the following two blocks, each untrained novel word will be presented twice per block.

Analytic Plan

Individual differences in language learning will be indexed through four outcome variables computed based on performance on the Translation task during the pre-tests, training blocks, and post-tests (see Table 2). The first outcome variable (Overall Learning) will measure overall learning for the three conditions across the four training sessions by indexing the relative difference in reaction time on the Translation task between the first pre-test (Day 2 – Training Session 1) and the last post-test (Day 5 – Training Session 4). The second outcome variable (Learning Rate) will measure rate of learning for the three conditions across the four training sessions by indexing the slope of a linear best-fit line to participant's accuracy on the Translation task across the twelve training blocks. The third outcome variable (Consolidation) will measure offline consolidation across the three conditions by indexing the relative difference in reaction time on the Translation task between the first post-test (Day 2 – Training Session 1) and the second pre-test (Day 3 – Training Session 2). Offline consolidation will only be examined after the first training session because the interval between the first and second training session will be fixed at 48 hours, while the intervals following the second and third training sessions may vary across participants. The fourth outcome variable (Generalization) will measure generalization of the morphological rules by indexing average reaction time on the Translation task during the untrained post-test (Day 5 – Training Session 4).

Table 2. Language training outcome variables.

	Operationalization
Overall Learning	(Training Session 1 Pre-test RT – Training Session 4 Post-test RT) / Training Session 1 Pre-test RT
Learning Rate	Slope of a linear function fit to each participant's accuracy across the training blocks (with the intercept fixed at the origin)

Consolidation	(Training Session 1 Post-test RT – Training Session 2 Pre-test RT) / Training Session 1 Post-test RT
Generalization	Training Session 4 Untrained Post-test RT

*Note: Each outcome variable will be computed separately for each condition. RT = average reaction time

Given the nature of the study design, in which the task conditions are nested within participants, multilevel modeling will be used to investigate condition differences across the four outcome variables. First, an unconditional random-intercept model will be estimated in order to estimate the interclass correlation coefficient, which represents the degree of dependence in the data. Then, a conditional random-intercept model that includes condition, working memory (mean centered), and morphological awareness (mean centered) will be estimated to evaluate condition differences. This two-step modeling approach will be repeated for each of the four outcome variables.

Q-Q, histogram, and bivariate plots will be used to evaluate the homoscedasticity and normality assumptions of the multilevel modeling approach, proper model specification, and the presence of extreme values. Violations of homoscedasticity will be addressed through the use of robust standard errors. Violations of normality will be addressed first by applying non-linear transformations and, if violations are still present, then through the use of generalized linear mixed effects modeling. Violations of model specification will be addressed by adding higher-order or non-linear terms to the model. The influence of extreme values will be evaluated through sensitivity analyses, in which models with and without the extreme values will be compared.

Predictions

According to the CLS theory (McClelland et al., 1995; McClelland, 2013; McClelland et al., 2020), which motivates the present work, learning is accelerated when new information is consistent with previously acquired knowledge. The current study will investigate whether this learning principle contributes to L2 morphological learning. In particular, this study will investigate the hypothesis that similarity between to-be-learned L2 morphological structures and morphological structures in one's L1 will contribute to L2 learning, and therefore learning will be facilitated in the L1-similar condition. In support of this hypothesis, it is predicted that the L1-similar condition will show greater overall learning, as indexed by a larger reduction in reaction times from the initial pre-test to the final post-test, a faster learning rate, as indexed by a steeper slope in accuracy across the training blocks, greater offline consolidation, as indexed by a larger reduction in reaction times following the first day of training, and greater generalization, as indexed by faster reaction times on the untrained post-test, as compared to the Simple and, more importantly, the L1-dissimilar condition.

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