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From Klingon to Colbertian: Using Artificial Languages to Study Word Learning

Sayuri Hayakawa[1], Siqi Ning[2] and Viorica Marian[3]

[1]Northwestern University; [2]Northwestern University and [3]Northwestern University

Review Article

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Address for correspondence:
Dr. Sayuri Hayakawa,
Email: sayuri.hayakawa@northwestern.edu

Abstract

Vocabulary acquisition is a critical part of learning a new language. Yet, due to structural, historical, and individual variability associated with natural languages, isolating the impact of specific factors on word learning can be challenging. Artificial languages are versatile tools for addressing this problem, allowing researchers to systematically manipulate properties of the language and control for learners' past experiences. Here, we review how artificial languages have been used to study bilingual word learning, with a particular focus on the influences of language input (e.g., word properties) and language experience (e.g., bilingualism). We additionally discuss the advantages and limitations of artificial languages for bilingual research and suggest resources for researchers considering the use of artificial languages. Used and interpreted properly, artificial language studies can inform our understanding of a wide range of factors relevant to word learning.

Introduction

Not yap wa' Hol. If asked to translate, speakers of Klingon (an alien language from the TV series, *Star Trek*) would tell you that "one language is not enough." Many would agree with this sentiment, judging by the ubiquity of multilingualism and the popularity of language learning platforms such as *Duolingo* – which, incidentally, offers Klingon. Beyond the utility for building imaginary worlds (as with Klingon, Elvish, or Dothraki), artificial languages can provide insight into how we acquire natural languages in the world around us. In fact, Klingon itself has been used to assess language learning aptitude, as the ability to map Klingon sounds to symbols can predict English language proficiency (Kiss & Nikolov, 2005). Artificial languages have proven to be useful and versatile tools for studying language acquisition by helping to control for the immense variability that exists within natural languages.

Over 7,000 natural languages are used worldwide, spanning more than 140 language families (Simons & Fennig, 2018). Languages can vary at every level of representation, including how they are written (e.g., alphabetic vs. logographic), pronounced (e.g., tonal vs. non-tonal), syntactically ordered (e.g., subject-verb-object vs. verb-subject-object), and expressed (e.g., vocally vs. manually). There is also variability within languages (e.g., words that differ in concreteness, frequency, pronounceability), and across language users (e.g., proficiency, exposure, cognitive abilities). As a result, isolating the influence of any one factor can be difficult, if not impossible, when studying natural languages. One of the primary advantages of using artificial languages is the flexibility to carefully control not only the learners' prior experience with a language, but also the properties of the language itself. It allows experimenters to customize their stimuli to fit the exact linguistic requirements of a particular study, while avoiding unwanted variability often found in natural languages (De Graaff, 1997).

One may question, however, whether learning a language stripped of idiosyncrasies can truly inform us about learning real languages. And certainly, even a fairly well-formed artificial language is bound to pale in comparison to the rich and vivid constellation of sensory inputs, linguistic structures, motor programs, thoughts, beliefs, and memories that become associated with natural languages. However, just as physicists can collide particles to study the origins of the universe, psycholinguists can use artificial languages to examine the linguistic system. Furthermore, the substantial overlap between artificial and real languages in neural activation (Friederici, Steinhauer & Pfeifer, 2002), as well as behavioral measures of second language learning aptitude (Ettlinger, Morgan-Short, Faretta-Stutenberg & Wong, 2016), speak to the ecological validity of using artificial languages in bilingualism research.

Within the broad area of artificial language learning, the present paper focuses on two lines of inquiry relevant to understanding bilingual word learning: the influence of language input, and the impact of bilingual experience. Together, these two components represent the wide spectrum of extrinsic (e.g., language) and intrinsic (e.g., learner) sources of variability that determine successful learning. After a brief overview on the origin and function of artificial languages, we provide concrete examples of how artificial languages have been used to study the effects of language and learner characteristics, ultimately shedding light on the emergence and consequences of bilingualism. Lastly, we consider the advantages and limitations of using artificial languages to study natural language processes, and suggest resources for constructing artificial languages before concluding with a discussion of potential future directions.

The origin and function of artificial languages

Artificial languages have had a long history, starting with Lingua Ignota created in the 1100s by a German abbess named Hildegard von Bingen. The use of artificial languages in research came much later, with American psychologist Erwin Allen Esper conducting one of the earliest artificial language studies in 1925. Around the same time, the artificial language of Esperanto, deliberately created to have highly regular morphological and syntactic rules, began to be taught in parts of Europe to help students understand parts of speech in their mother tongue, as well as to learn other Romance languages (Eaton, 1927). In research, artificial languages are often created to examine specific levels of representation, such as the BROCANTO (Friederici et al., 2002) and BROCANTO 2 languages (Morgan-Short, Sanz, Steinhauer & Ullman, 2010; Morgan-Short, Steinhauer, Sanz & Ullman, 2012), which have artificial grammars suitable for studying morphosyntactic processing. Artificial languages have also been used to simulate the emergence of natural languages (Van Trijp, 2010). Lastly, research using artificial languages can systematically vary linguistic parameters to facilitate investigations into the specific characteristics of languages and learners that contribute to effective word learning.

Using artificial languages to study the role of language input in word learning

The value of artificial languages is perhaps most transparent when examining the influence of particular *word properties* on second language vocabulary acquisition. For example, to investigate whether similarity to the native language (L1) facilitates novel word learning, Bartolotti and Marian (2017) created a "wordlike" and "unwordlike" version of an artificial language called Colbertian (named after Stephen Colbert, comedian and inventor of neologisms such as "truthiness"). The two versions were constructed to either follow or violate the English rules for combining letters and sounds into words (e.g., *nish* vs. *gofp*) by manipulating orthographic neighborhood size (many or few similarly-written English words) and orthotactic probability (high or low likelihood of observing the novel word's letter sequence based on English patterns). In all other respects, the two versions were matched (e.g., their English translations, word length, etc.). After training and testing native English speakers on one of the versions, the researchers found that recognition and production were faster and more accurate for the wordlike language (see Figure 1 for example training and recognition test trials). Artificial language studies have revealed that learning can also be influenced by properties of the novel word's translation, such as cognate status (de Groot & Keijzer, 2000), as well as word frequency (de Groot, 2006). Novel word forms are also more likely to be recalled if they are associated with concrete rather than abstract concepts (de Groot & Keijzer, 2000; de Groot, 2006), demonstrating that how well we learn new words depends on properties at multiple levels of representation, including the phonological, orthographic, lexical, and semantic characteristics of both known and unknown words.

Investigating the factors that facilitate word learning can serve a practical function by informing instructors and students about what is likely to be more or less difficult to learn. Perhaps more significant, however, are the theoretical insights that can be derived from observing the variables that help and hinder second language word learning. For instance, the finding that concrete words are learned more readily than abstract words may have implications for how we conceptualize the structure of bilingual memory. There is evidence that the relationship between L2 words and their concepts is lexically mediated during early stages of word learning, so L2 words initially activate conceptual information via connections to L1 word forms (e.g., "nish" → "apple" → *apple concept;* see Kroll & Stewart's (1994) Revised Hierarchical Model). The fact that semantic properties (e.g., concreteness) can affect how easily a learner is able to access an L1 translation suggests that L2 words can also directly activate conceptual representations in parallel, or before, activating L1 translations (e.g., "nish" → *apple concept* → "apple"; Potter, So, Von Eckardt & Feldman, 1984).

Other cases of *conceptual mediation* have been observed in studies that manipulate the *linguistic context* in which artificial words are embedded (e.g., word sets, sentences, streams of speech). For instance, learning artificial words in semantically-related sets (e.g., apple, orange, grape) can make it more difficult to produce their L1 translations, suggesting that conceptual information can interfere with the retrieval of L1 lexical information (Finkbeiner & Nicol, 2003; Tinkham, 1993). This result indicates that the way we are exposed to a word can significantly impact acquisition. Artificial languages are therefore often used to identify linguistic contexts that facilitate learning (e.g., Kersten & Earles, 2001), as well as to understand how words embedded in challenging contexts are learned at all. The latter is particularly relevant to understanding how children exposed to multiple languages manage to extract the linguistic structures contained in two different, potentially inconsistent sources of information. Researchers are able to gain insight into this process by seeing how learners track statistical regularities from continuous streams of artificial words (e.g., Mitchel & Weiss, 2010) and tones (e.g., Bartolotti, Marian, Schroeder & Shook, 2011). For instance, it has been found that learners can rely on nonlinguistic cues (such as the voices and faces of speakers) to distinguish between languages and learn the distributional properties of each one (Weiss, Gerfen & Mitchel, 2009; Mitchel & Weiss, 2010).

In sum, artificial languages have been used to demonstrate that the ease of acquiring novel vocabulary differs depending on characteristics of the language to be learned, such as similarity to known languages and concreteness, as well as the surrounding linguistic context, such as adjacent words and sounds. These findings, in turn, inform our understanding of the structures and processes that enable the acquisition of multiple languages. See Table 1 for a summary of the reviewed studies examining the influence of language input on word learning.

Using artificial languages to study the role of bilingual experience in word learning

Early in development, differences emerge in how monolingual and bilingual children learn words. When presented with a novel word and an array of possible referents, children have a strong tendency to infer that the label belongs to an unfamiliar, rather than a familiar object (i.e., "mutual exclusivity;" Markman & Wachtel, 1988). However, studies using both artificial (Davidson, Jergovic, Imami & Theodos, 1997) and natural languages (e.g., Byers-Heinlein &

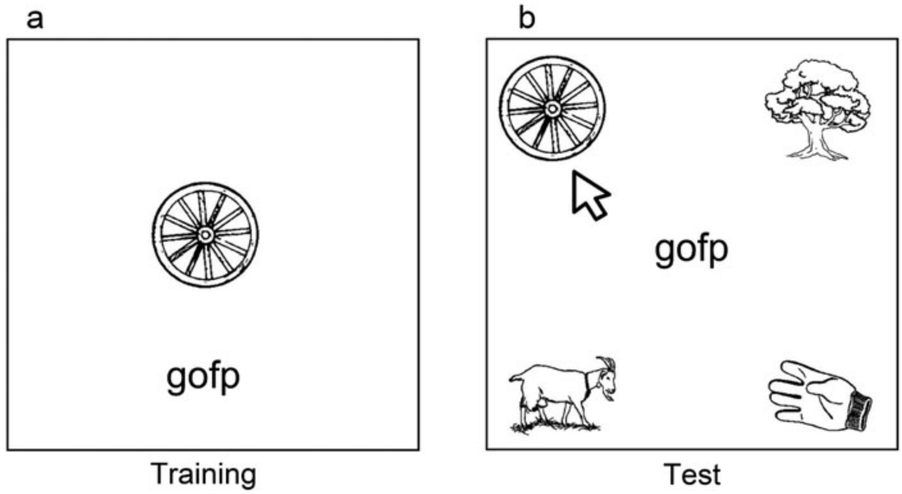

Fig. 1. Examples of Colbertian (a) training and (b) recognition test trials in the "unwordlike" condition (Bartolotti & Marian, 2017).

Werker, 2009) have found that bilingual children are less constrained by mutual exclusivity, likely as a result of learning early on that objects often have two labels. Monolingual and bilingual children also rely on different sources of information to identify the referents of artificial words (Brojde, Ahmed & Colunga, 2012). While monolinguals tend to focus on perceptual cues, such as an object's shape or color, bilinguals rely more on pragmatic cues, such as the eye gaze of people around them, possibly because of exposure to more complex social and linguistic environments. These findings demonstrate that bilingual experience can alter how children map words to meaning.

In addition to learning words differently, bilingual children and adults often learn words more effectively than monolinguals (e.g., Kaushanskaya & Marian, 2009a; Menjivar & Akhtar, 2017; see Hirosh & Degani, 2018 for a review). These advantages for language learning have been linked to both better phonological working memory and executive control (e.g., Antoniou, Liang, Ettlinger & Wong, 2015; Kaushanskaya & Marian, 2009a), as either could potentially increase an individual's ability to learn novel words (Kapa & Colombo, 2014; Papagno, Valentine & Baddeley, 1991). Greater phonological working memory and experience with diverse speech sounds could improve comprehension of foreign phonemes, and consequently, word learning (Kaushanskaya & Marian, 2009a), while greater cognitive control could help bilinguals inhibit interference from conflicting information. Take, for example, Yoshida, Tran, Benitez, and Kuwabara's (2011) finding that bilingual children outperform monolinguals on measures of both cognitive control and artificial adjective learning. The researchers interpreted this language learning advantage as stemming from more effective inhibition of word learning heuristics (such as the tendency to assume that labels refer to nouns). Similarly, Bartolotti and Marian (2012) proposed that extensive experience managing conflict across multiple languages may make bilinguals especially adept at inhibiting lexical competition. In one study, Kaushanskaya and Marian (2009b) had English monolinguals and English-Spanish bilinguals learn novel artificial language words with orthography-to-phonology mappings that differed from their native tongue. During control trials, participants would read an English word such as HOCKEY while listening to the novel word translation, pronounced /χf/. During critical trials, participants would additionally see the written form of the novel word, GEF, which did not correspond to its phonology based on English rules. While bilinguals generally outperformed monolinguals on subsequent vocabulary tests, this was especially the case for trials that included orthography-to-phonology mappings that conflicted with those in known languages. Yoshida et al. (2011) and Kaushanskaya and Marian (2009b) thus demonstrate two different ways in which bilingual experience can enhance word learning in children and adults, respectively: the former by reducing interference from heuristics within a single language, and the latter by reducing interference from orthography-to-phonology mappings of other known languages.

As with studies explicitly examining the role of language input, using artificial languages to study group differences can help reduce unintended variation across stimuli and the likelihood of spurious effects. In Kaushanskaya and Marian (2009b), using artificial languages made it possible to systematically manipulate the extent to which orthography-to-phonology mappings aligned with the learners' known languages (while ensuring that other word properties, such as biphone and bigram probabilities, were equidistant from both known languages). An equally important function when comparing monolinguals to bilinguals, however, is the ability to ensure that neither group has had prior exposure to the novel language. This can be especially useful for experiments that include bilinguals from multiple different language backgrounds (as they often do). In Yoshida et al. (2011), for instance, using artificial words ensured that the stimuli were novel to all participants in their heterogeneous sample, whether their second language was Chinese, French, Spanish, Russian, Urdu, or Vietnamese. Converging evidence using natural languages (e.g., Van Hell & Mahn, 1997; Keshavarz & Astaneh, 2004), however, is valuable for ensuring that effects based on highly controlled, simplified languages are generalizable to richer, more complex languages. In sum, artificial languages have been used to shed light on how children learn words in different language environments, as well as why bilingual experience facilitates learning. See Table 2 for a summary of the reviewed studies examining the impact of bilingual experience on word learning.

Conducting artificial language research: Limitations, opportunities, and resources

One limitation of both artificial and natural languages is that even strict controls cannot fully prevent the influence of unintended variables, as learning can be impacted by not only the word to

Table 1. Examples of studies examining effects of linguistic input on artificial language learning

Study	Study Focus	Artificial Language Stimuli	Method	Results
Bartolotti & Marian (2017)	Effect of native-language similarity	*Colbertian:* orthographically wordlike (e.g., *nish*) and unwordlike (e.g., *gofp*) words, paired with line drawings.	20 English monolinguals learned picture-word pairs and were tested on production and recognition (with feedback).	Participants were faster and more accurate at recognizing and producing wordlike items.
de Groot (2006)	Effects of word frequency, typicality, concreteness, and background music	Dutch-nonword pairs, controlling for frequency and concreteness of Dutch words & phonotactical typicality of the nonwords.	36 Dutch speakers learned Dutch-nonword pairs over six blocks with or without background music. Tested on production of Dutch translations during and 1 week after training.	Background music, greater typicality, word frequency, and concreteness facilitated word learning.
de Groot & Keijzer, (2000)	Effects of concreteness, cognate status and word frequency on "word-association" learning and retention	Dutch-nonword pairs, with manipulations of word concreteness, cognate status, and word frequency.	40 Dutch speakers learned Dutch-nonword pairs over six blocks. Tested on either a productive (see Dutch word, produce nonword) or a receptive task (see nonword, produce Dutch translation) during and 1 week after training.	Cognates and concrete words were easier to learn. Word frequency hardly affected performance. Receptive testing showed better recall than productive testing.
Finkbeiner & Nichol (2003)	Effect of semantic grouping on vocabulary acquisition	Nonwords conforming to English phonotactic constraints, paired with pictures of familiar concepts in 4 semantic categories. Half monosyllabic (e.g., *birk*) and half disyllabic (e.g., *walloon*).	47 monolingual English speakers learned new L2 labels for concepts in either semantically related or unrelated clusters. At test, participants translated words in both translation directions.	Semantic grouping has negative effects on learning.
Kersten & Earles (2001)	Effect of small-segment processing	Sentences of 3 nonwords, with different morphemes referring to the object, path, and manner of motion in an animation.	112 participants were trained with animation-sentence pairs, with some learning full sentences throughout and others learning words incrementally. Isolated and embedded word meaning were tested.	Acquiring words in small segments was more conducive to learning than seeing full sentences throughout learning.
Mitchel & Weiss (2010)	Effect of visual speaker identity cues on the segmentation of multiple speech streams	4 artificial languages each consisting of 4 trisyllabic (CV.CV.CV) nonwords, randomly ordered and concatenated into a continuous stream.	40 English monolinguals heard two incongruent artificial speech streams produced by the same female voice along with an accompanying visual display of two talking faces, a single face, two talking faces lacking audio-visual synchrony, or a static face. A single face paired with a single stream was also tested.	Learners successfully segmented both streams only when the audio stream was presented with an indexical cue of talking faces with temporal synchrony to the speech sounds.
Tinkham (1993)	Effect of semantic grouping on vocabulary acquisition	English-nonword pairs, controlling for number of syllables, stress, and vowel-consonant patterns.	20 English speakers learned English-nonsense word pairs in semantically related or unrelated clusters through multiple exposures in two experiments. Tested on production of English translations.	Semantic grouping has negative effects on learning.
Webb (2005)	Effects of receptive and productive vocabulary learning	Japanese-nonword pairs either accompanied by 3 English glossed sentences containing the target word (receptive treatment) or a blank space (production treatment).	66 Japanese EFL students learned nonwords either by reading 3 glossed sentences or by writing an English sentence containing the nonword. Tested with 10 receptive and productive tasks on orthography, syntax, association, grammatical functions, and meaning.	Receptive learning was superior if learning time was controlled. Productive learning was superior if given time as needed.
Weiss, Gerfen & Mitchel (2009)	Effect of bilingual language input on statistical learning	4 artificial languages each consisting of 4 trisyllabic (CV.CV.CV) nonwords, randomly ordered and concatenated into a continuous stream, read by a male and a female voice.	In four experiments, English monolinguals listened to a speech stream of multiple languages and indicated which of two strings sounded more like a word from the languages. Congruency and voice cues between interleaved languages were varied across experiments.	When confronted with bilingual input, learners can track two sets of statistics simultaneously, suggesting that they form multiple representations.

Table 2. Examples of studies examining effects of bilingualism on artificial language learning

Study	Study Focus	Artificial Language Stimuli	Method	Results
Bartolotti, Marian, Schroeder & Shook (2011)	Effect of bilingualism and inhibitory control on statistical learning of novel language	2 novel languages based on the International Morse Code. In low-interference condition, words marked by between-letter statistical probabilities. In high-interference condition, between-word transitional probabilities and pauses compete as boundary cues.	Participants listened to a continuous stream of words in a Morse code language to test their ability to segment words. Next, they listened to a new language with words that conflicted with the first Morse code language. Tested on word knowledge with forced-choice.	Bilingual experience can improve word learning when interference from other languages is low, while inhibitory control ability can improve word learning when interference from other languages is high.
Brojde, Ahmed & Colunga (2012)	Effect of bilingualism on children's perceptual and pragmatic cue reliance in novel word learning	Novel names (*zuly*, *flone*, *deej*, and *tizo*) were applied to 4 exemplar objects, each with 8 objects that match the exemplar in either shape, color, texture, or two of the above.	32 two- to three-year-old monolingual and bilingual children were given the name of a novel exemplar and asked to generalize the name to other novel objects matching in different properties under different cue conditions.	When perceptual and pragmatic cues were inconsistent, monolingual children attend more to object property cues and bilingual children attend more to pragmatic cues.
Davidson, Jergovic, Imami & Theodos (1997)	Effect of bilingualism on children's use of the mutual exclusivity constraint, when objects have two names in the same language	Artificial names were nonsense words either in English, Urdu, or Greek (e.g., *bave*).	96 three- and six-year-old monolingual and bilingual children completed disambiguation, rejection, and restriction tests. In the disambiguation and rejection tasks, children were given nonwords and asked to assess which objects they refer to.	On both disambiguation and rejection tests, the mutual exclusivity bias was more evident in five- and six-year-old monolingual children than in their same-age bilingual peers.
Kaushanskaya & Marian (2009a)	Effect of bilingualism on novel word learning	Disyllabic nonwords created from 4 English and 4 non-English phonemes, paired with phonologically dissimilar, high-frequency, concrete English words. Nonwords were unwordlike in English, Spanish, and Mandarin.	60 English monolinguals, early English-Spanish bilinguals, and early English-Mandarin bilinguals were familiarized with English-nonword pairs through auditory and visual input, and oral repetitions. Tested on recall and recognition immediately and 1 week later.	At testing, both bilingual groups outperformed the monolingual group, indicating that bilingualism facilitates word-learning performance in adults.
Kaushanskaya & Marian (2009b)	Effect of bilingualism on ability to resolve cross-linguistic inconsistencies in orthography-to-phonology mappings in novel word learning	See Kaushanskaya & Marian (2009a).	48 English monolinguals and Spanish-English bilinguals read English words while listening to novel word translations, or additionally saw written novel words. Tested using production and recognition tasks immediately and after 1 week.	Bilinguals generally outperformed monolinguals on subsequent vocabulary tests, especially for trials that included conflicting phonological and orthographic information.
Menjivar & Akhtar (2017)	Effect of bilingualism on children's novel word learning abilities	*Nordish*: phonotactically legal nonwords in both English and Spanish paired with colored photographs of familiar and novel objects	48 four-year-old English speakers who were monolingual, bilingual, or regularly exposed to a second language learned *Nordish* in 4 training blocks, with each block immediately followed by a comprehension test.	When task demands were high, bilinguals learned more words than monolingual children, and exposed children's performance fell between the two, suggesting an early bilingual word learning advantage.
Yoshida, Tran, Benitez & Kuwabara (2011)	Effect of bilingualism on children's novel word learning abilities and attentional control	Four novel adjectives: *blickish, dakish, talish,* and *waggish*, which referred to objects that were string-wrapped, pipe-cleaner-attached, a surface made out of soft sponge pieces, and a Velcro surface.	40 three-year-old monolingual and bilingual children participated in one attentional control task and one novel adjective task, where the child was asked to pick an object out of two with either a known (e.g., bumpy) or a novel made-up adjective.	Bilingual children showed advanced attentional control, which may have contributed to their superior novel adjective learning.

be learned, but any word or concept associated with it. Note, however, that artificial languages still have an advantage over natural languages in this respect, as the latter introduce potential confounds for both novel and known languages. Yet studies using natural language stimuli can and do provide valuable insights, and their inherent complexity and richness can be an advantage in addition to an obstacle. Though artificial and natural language studies often converge upon the same conclusions, there may be cases in which discoveries based on natural language stimuli (e.g., French words) more reliably translate to real-world contexts (e.g., learning French in a lab vs. school), particularly given the impact that specific language properties can have on word learning. Highly-controlled artificial languages, on the other hand, are especially useful for reducing confounds and establishing causal mechanisms (e.g., enhanced inhibitory control), which can inform the generalizability of competence across different skill sets (e.g., learning language vs. music).

The utility of artificial languages for revealing causal mechanisms may additionally offer the opportunity to better understand cases in which bilinguals appear to have language learning difficulties, either due to legitimate language disorders, or less familiarity with the language being tested. Within the clinical field of Speech-Language Pathology, approaches such as Dynamic Assessment (Hasson, Camilleri, Jones, Smith & Dodd, 2013) are often used to determine whether children who struggle on traditional language aptitude tests are able to acquire novel language rules (see Gutieérrez-Clellen & Penña, 2001). By controlling for potential confounds related to unintentional conflict or overlap with known languages, future research using artificial languages may help clinicians distinguish between language differences and language disorders among children from linguistically and culturally diverse backgrounds.

For individuals conducting their own word learning research using artificial languages, there are a number of useful resources available (Marian, 2017). The CLEARPOND (Cross-Linguistic Easy-Access Resource for Phonological and Orthographic Neighborhood Densities) can be used to calculate and control for properties such as phonological and orthographic biphone and bigram frequencies, as well as neighborhood size and density, when creating words in an artificial language (Marian, Bartolotti, Chabal & Shook, 2012). Databases such as SUBTLEX contain word frequency information in several languages including English (Brysbaert & New, 2009), German (Brysbaert, Buchmeier, Conrad, Jacobs, Bölte & Böhl, 2011), and Chinese (Cai & Brysbaert, 2010). Other tools such as the Simple Natural Language Processing tool (Crossley, Allen, Kyle & McNamara, 2014) can be used to analyze elements of discourse processing, such as syntactic complexity. While it should be noted that the majority of resources are based on English and other Indo-European languages, tools such as CLEARPOND allow users to upload custom lists to calculate lexical neighborhood statistics. These and other similar resources make it possible to use information about natural languages as a basis to generate artificial language stimuli with variable degrees of similarity to real languages (e.g., Bartolotti & Marian, 2017). They can also be used to control the natural language translations of artificial words (e.g., de Groot & Keijzer, 2000), as well as any natural language stimuli that may be integrated with artificial languages (e.g., Webb, 2005).

Concluding remarks

At face value, learning a word may seem like a trivial task. Upon closer examination, it becomes apparent that the ability to learn a word belies an intricate system of perceptual schemas, cognitive functions, linguistic representations, and conceptual knowledge – made particularly complex with the introduction of multiple languages. With properly controlled stimuli, however, the ability to learn a word can provide significant insight into how the bilingual cognitive system functions. Because artificial languages allow fine-grained control over linguistic properties and prior language exposure, they can be useful tools to investigate how word learning is influenced by external factors, such as the language to be learned, as well as learner characteristics, such as language experience.

Understanding how words are learned has obvious practical utility, whether it is in service of diagnosing and treating language or learning disorders or in facilitating the acquisition of foreign languages. More fundamentally, however, how we learn words reflects our capacity to understand, generate, and see relationships among a system of symbols. This ability, which emerges early and universally in human development, is the very basis of complex reasoning and abstract thought – one that appears to out-pace all other animals and has proven difficult for artificial intelligence and machine learning. Though artificial languages, so far, have primarily been used to study how we learn rules and structures that are inherently tied to language (such as phonology, orthography, morphology, and syntax), future research may address the open question of whether artificial languages can be profited from to better understand the more generative side of language and the development of higher-order functions, such as analogical reasoning and event structure learning. With their capacity to distill complex processes down to their critical components, artificial languages may hold the key to understanding uniquely human abilities that continue to confound even the most advanced forms of artificial intelligence.

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