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Statistical Learning of a Morse Code Language is Improved by Bilingualism and Inhibitory Ability

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Abstract

We examine the influence of bilingualism and inhibitory control on the ability to learn a novel language. Using a statistical learning paradigm, participants learned transitional probabilities in two novel languages based on the International Morse Code. First, participants listened to a low-interference language to test word segmentation skill. Next, participants listened to a high-interference language, in which a colliding cue to word boundaries in the form of compressed pauses between words conflicted with the language's transitional probabilities. Results suggest that high proficiency in a second language can improve word learning in a novel language, but when interference during learning is high, language experience no longer confers a benefit and strong inhibitory control ability is necessary for learning to occur.

Keywords: language acquisition; bilingualism; pattern recognition

Introduction

Language learning is a complex phenomenon that requires the learner to incorporate novel phonology, vocabulary, and grammatical rules. Not surprisingly, acquiring a new language can be difficult, particularly later in life, and many learners never achieve full native-like proficiency (Birdsong, 2006; 2009; DeKeyser, 2005). Learning outcomes may be improved by identifying the processes that contribute to successful acquisition of a novel language. One of the first steps to language acquisition is to understand the way in which sounds are combined to create words. After identifying novel sound sequences, they can be assigned to semantic concepts and the complete word added to one's vocabulary. Here we consider how two related factors, bilingual language experience and inhibitory control, may influence this word acquisition process.

Bilingualism has been shown to provide a language learning advantage, and bilinguals acquiring a third language outperform monolinguals acquiring a second language (Cenoz & Valencia, 1994; Kaushanskaya & Marian, 2009a; 2009b; Keshavarz & Astaneh, 2004; Sanz, 2000; Thomas, 1992). This may be due in part to bilinguals' enhanced working memory, which allows them to sustain novel words in the focus of attention until they can be encoded in long-term memory (Papagno & Vallar, 1995; van Hell & Mahn, 1997), and is linked to high second-language proficiency (Majerus, Poncelet, van der Linden, & Weekes, 2008; Service, Simola, Metsänheimo, & Maury, 2002). These novel words may be more readily linked to novel sound sequences at the phonological level, or mapped onto concepts shared with translation equivalents at the semantic level. Increased flexibility in either of these processes would allow for accelerated vocabulary acquisition in bilinguals, leading to rapid gains in novel language knowledge.

Vocabulary learning is particularly important in attaining language fluency; by some estimates learners need to know 98% of the words they hear to comprehend speech which translates to roughly 8000 lexical items (Nation, 2006). The size of vocabularies means that many words are acquired incidentally, either by reading or listening to speech (Schmitt, 2008). Words acquired from speech are notoriously difficult to learn, in part because the boundaries between words are not always obvious. One way to overcome the word boundary problem is to attend to the regularities in speech. Sounds that co-occur often are likely to comprise part of a single word, whereas rare sound sequences are likely to mark transitions between words. These transitions can mark the beginning of novel words, which should be attended to and encoded by the learner. Infants demonstrate attention to statistical probabilities in a continuous auditory sequence (Saffran, Aslin, & Newport, 1996), as do adults (Saffran, Johnson, Aslin, & Newport, 1999), and this skill has been associated with word-learning ability (Mirman, Magnuson, Estes, & Dixon, 2008). It is a flexible process that can be applied to successfully learn words composed of speech phonemes, musical tones, or visual sequences (Saffran, et al., 1999; Slemmer, Kirkham, & Johnson, 2010), and may reflect the process by which language learners acquire words from spoken speech.

A potential difficulty during novel language acquisition remains, though, in that the novel language is prone to interference from already known languages. Interaction between languages is observed during language processing and can lead to interference (Bijeljac-Babic, Biardeau, & Grainger, 1997; Blumenfeld & Marian, 2007; Duyck, Assche, Drieghe, & Hartsuiker, 2007; Marian & Spivey, 2003a; 2003b; Schwartz & Kroll, 2006; van Heuven, Dijkstra, & Grainger, 1998). In the process of acquiring a new language, interference from known languages may be particularly destructive, as known languages are highly practiced and may activate more easily. Better suppression of non-target language activation may consequently improve attention to novel language cues and facilitate acquisition.

Inhibitory control ability is one way to manage this interference, by reducing activation of irrelevant items. Strong inhibitory control has been associated with improved statistical learning in situations where interference during learning was particularly pronounced (Weiss, Gerfen, & Mitchel, 2010). Bilinguals display advantages in inhibitory control compared to monolinguals on non-linguistic tasks involving distracting cues (Bialystok, 1999; 2007; Bialystok, Craik, Klein, & Viswanathan, 2004; Costa, Hernández, & Sebastián-Gallés, 2008), which may also contribute to their language learning ability by suppressing interference and increasing the saliency of novel words.

To separately investigate the influences of bilingual experience and inhibitory control, we tested participants who varied in second language proficiency and level of inhibitory control on their ability to learn two languages that were based on the International Morse Code. Morse code is different from natural languages in that all information is conveyed rhythmically by changes in duration of pure tone sequences and silences. Morse code is sufficiently difficult to learn to discriminate learners from non-learners, and because it does not overlap in form with any languages participants knew, it avoids favoring speakers of one language over another. Since overlap with participants' known languages was low, we were able to create a low-interference condition in which learning required detecting statistical regularities within the Morse stream, but did not require inhibiting competitive interference from known languages. Because the inhibitory demands were reduced, the low-interference condition allowed us to assess whether proficiency in a second language has an effect on incidental word learning from speech, independent of inhibitory control ability.

In addition to the low-interference condition, we also designed a second, high-interference condition to assess the influence of inhibitory ability on word segmentation. The words in this second, high-interference condition conflicted with the previously-learned words in the low-interference condition. Additionally, a colliding cue to word boundaries that conflicted with the transitional probabilities between words was inserted to create interference within the new language itself, a paradigm shown to recruit inhibitory control (Weiss et al., 2010). Learning in our high-interference condition depended on both suppressing the first Morse code language and selectively attending to one of the two sets of word boundary cues (by inhibiting the other) in the second Morse code language. The second, high-interference condition therefore enabled us to examine the influence of inhibitory ability on word segmentation in contexts where learners have to reduce interference from conflicting linguistic information.

To summarize, in the present study, we examined the contributions of second language experience and inhibitory control to word segmentation. Participants who varied in second language experience and level of inhibitory control were taught Morse code words in a low-interference condition and a high-interference condition. The low-interference condition placed few demands on inhibition; in this condition, high proficiency in a second language was expected to contribute to successful word segmentation. The high-interference condition placed high demands on inhibition; in this condition, inhibitory ability was expected to promote successful word segmentation.

Method

Participants

Twenty-four Northwestern University students (Mean age = 21.6, SD = 2.23) participated for course credit. Participants completed the LEAP-Q (Marian, Blumenfeld, & Kaushanskaya, 2007) to provide information about language proficiency and language use. Age of second language acquisition ranged from 0-14 (M = 7.78, SD = 4.92) A version of the Simon task was used to assess participants' inhibitory control ability. Median splits were used to separate participants into high/low second-language proficiency (composite of L2 oral production and comprehension: median of 5, scale of 0-10), and strong/weak inhibitory control (Simon effect: median of 33.2 ms). While some studies find a relationship between second language experience and inhibitory control (Bialystok, 2007), others do not (Morton & Harper, 2007). In the current study, second language proficiency and inhibitory control were not correlated ($r = -0.35$, $p > 0.1$), allowing their effects on learning to be considered independently.

Materials

Two artificial languages were created based on the international Morse code alphabet. In Morse code, letters are composed of combinations of short tones, or 'dots' (440Hz for 100ms) and long tones, or 'dashes' (440Hz for 300ms). A short pause (100ms) separates tones within a letter, and a long pause (300ms) separates letters within a word. Three words were created for each language such that the length of each word was a constant 1100ms, and no letter was used twice (See Table 1).

Table 1: Morse Code Languages

Language 1	--/. (ME)	-./.. (NI)	.-/- (AT)
Language 2	./-- (EM)	../-. (IN)	-/.- (TA)

Note: English translations were never shown to participants

Morse code training streams were created for each language with two restrictions: a word could not immediately follow itself, and each word was followed by the other two words an equal number of times. Since the first letter of each word perfectly predicted the second letter, transitional probability within-words was a constant 1.0. Since each word could be followed by either of the two other words, the between-word transitional probability was a constant 0.5.

The training stream in the low-interference condition had a 300ms long pause inserted between words, identical to the long pause that separated letters within a single word. To learn the words, participants would have to attend to the transitional probabilities within and between words (see Figure 1A). In contrast, the training stream in the high-interference condition replaced the long pause between

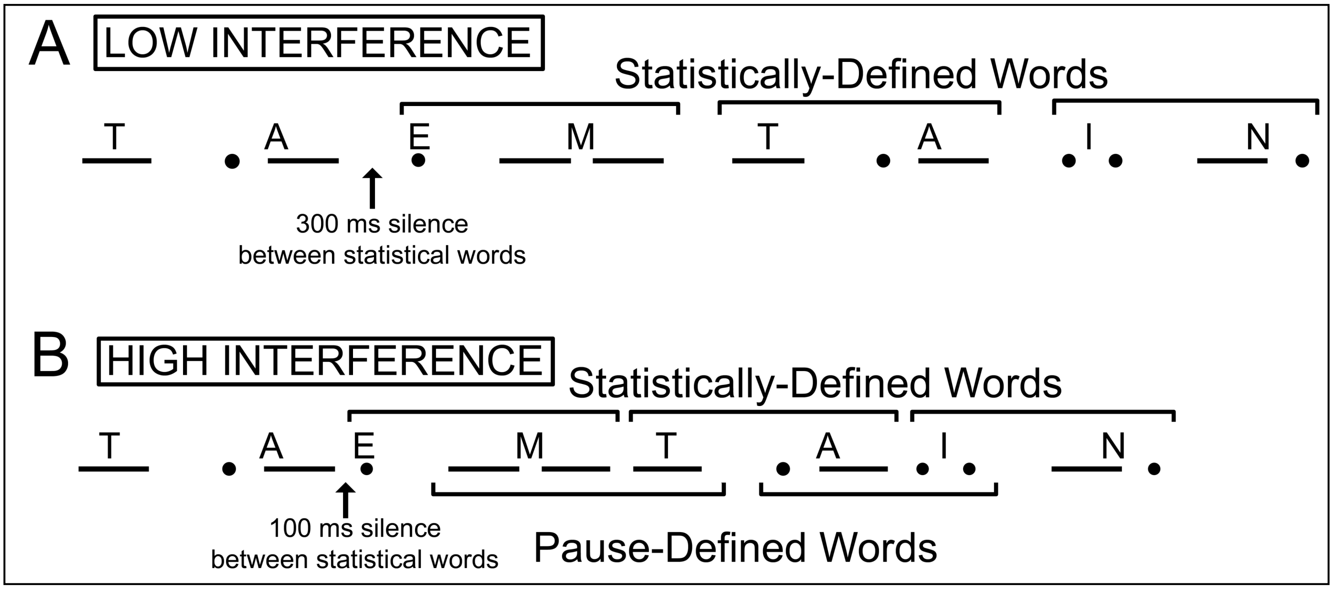

Figure 1: Morse code listening streams. Dots and dashes represent 100 ms and 300 ms tones, short and long gaps represent 100 ms and 300 ms silences. In the low interference condition, words are marked by statistical probabilities between letters (e.g., A follows T, but either E or I follow A). In the high interference condition, the gap between words is reduced, and the statistically defined words (TA, EM, IN) compete with words defined by the long pauses (AE, MT, AI).

words with a 100ms short pause, identical to the short pause that existed between elements within a single letter. The 300ms long pause between letters within a single word remained, only this pause now marked a competing word boundary. There were thus two colliding cues to word boundary: the between-word transitional probabilities (as in the low-interference condition), and the pause-based cues (see Figure 1B). To learn the words, participants would have to inhibit one of the two word-boundary cues and attend to the other.

Procedure

The Morse code language associated with each condition was counterbalanced across participants, but the order of the two conditions was fixed, with all participants completing the low-interference condition first, followed by the high-interference condition. This was done to ensure that no previously learned Morse code words could compete with targets during the low-interference condition. Learned words would then have to be inhibited during the following high-interference condition, adding to its inhibitory demands.

At the beginning of each learning condition, participants were instructed to listen to a series of tones and were told that they would be tested on information about the tones later. Participants wore headphones and listened to the Morse code stream over three blocks, each four minutes and twelve seconds long. Participants received a one-minute silent break between blocks.

Immediately after the third training block, participants were tested on their knowledge of the language with a twelve-item two-alternative forced-choice task. Participants were instructed to indicate which of two Morse code words was more familiar by pressing the '1' (first word) or '9' (second word) key on a computer keyboard. Word pairs were presented with a one-second pause between words, and a four-second pause between trials. Each of the three words was presented in four trials: twice before and twice after two different part-words. Part-words were created by concatenating the second letter from one word with the first letter of another word, and had appeared in the listening stream half as often as the actual words. In the high-interference condition, the part-words were words that could have been learned by using pause-based cues instead of statistical cues. Accuracy scores were obtained and normalized to chance performance, with a score of zero indicating six out of twelve correct. In the low-interference condition, positive scores above chance indicated word learning. In the high interference condition, positive scores above chance also indicated word learning based on the statistical cues, while negative scores indicated learning based on the pause cues. Either type of learning was a valid way of parsing the Morse code stream, but they entailed different inhibitory demands. The pauses competed with the statistical cues only, while the statistical cues competed with both the pauses and the previously learned words (due to overlapping letters between conditions). Learning by pauses in the high-interference condition may thus reflect a strategy that minimizes competition during learning and reduces inhibitory demands.

All participants also completed a visual Simon task to index inhibitory control. Participants viewed blue and brown rectangles that appeared on the left, right, or center of a computer screen and selected a response based on the item's color, while ignoring its location. The instructions were to press a blue button on the left side of the keyboard if the rectangle was blue, or to press a brown button on the right side of the keyboard if the rectangle was brown. In Congruent trials, the stimulus and the response were on the same side (e.g., a blue rectangle on the left side of the screen). In Incongruent trials, stimulus and response were on opposite sides (e.g., blue rectangle on the right side of the screen). In Neutral trials, the stimulus appeared in the center of the screen. Congruent, Incongruent, and Neutral trials appeared in an equal ratio. A single trial involved (1) a fixation cross for 350ms, (2) a blank screen for 150ms, (3) a colored rectangle for 1500ms, (4) in the event of an error, a red 'X' as feedback for 1500ms, and (5) a blank screen for an 850ms inter-trial interval. All participants completed a practice session before the actual task. The Simon effect was calculated by subtracting reaction time on Congruent trials from reaction time on Incongruent trials. A small Simon effect indicates better ability to ignore the inconsistent location cue, and improved inhibitory control.

Results

Second Language Proficiency

Experience in a second language positively influenced ability to learn in the low-interference condition, but did not affect ability to learn in the high-interference condition (Figure 2). Successful learning was characterized by greater than chance performance. In the low-interference condition, those with high proficiency in an L2 were able to learn (M = 2.41, SD = 2.01; $t(10) = 3.97$, $p < 0.01$), while those with low L2 proficiency did not learn (M = 1.09, SD = 2.34; $p > 0.1$). In the low-interference condition, second language proficiency was marginally correlated with learning, r = 0.40, $p = 0.06$. In the high-interference condition, neither the high L2 proficiency group (M = -0.27, SD = 2.10; $p > 0.1$) nor the low L2 proficiency group (M = -0.09, SD = 1.70; $p > 0.1$) were able to learn, and second language proficiency was not correlated with learning, r = 0.01, $p > 0.1$ (Figure 2).

Inhibitory Control

Strong inhibitory control was associated with increased learning of a second Morse code language in the high-interference condition, but did not discriminate learners of the first Morse code language in the low-interference condition (Figure 2). Both strong and weak inhibitory control groups successfully learned the Morse-code language in the baseline low-interference condition (strong inhibitory control: M = 1.79, SD = 2.46; $t(11) = 2.52$, $p < 0.05$; weak inhibitory control: M = 1.92, SD = 1.98; $t(11) = 3.36$, $p < 0.01$); inhibitory control was not correlated with learning, r = -0.25, $p > 0.1$. When these same participants were compared in their ability to learn a subsequent Morse code language in the high-interference condition, participants with strong inhibitory control demonstrated learning according to the pause-based rules (M = -1.18, SD = 1.60; $t(10) = -2.45$, $p < 0.05$), while participants with weak inhibitory control did not demonstrate learning (M = 0.58, SD = 1.73; $p > 0.1$). The difference between groups was significant ($t(21) = -2.53$, $p < 0.05$), and inhibitory control was correlated with learning, r = 0.47, $p < 0.05$.

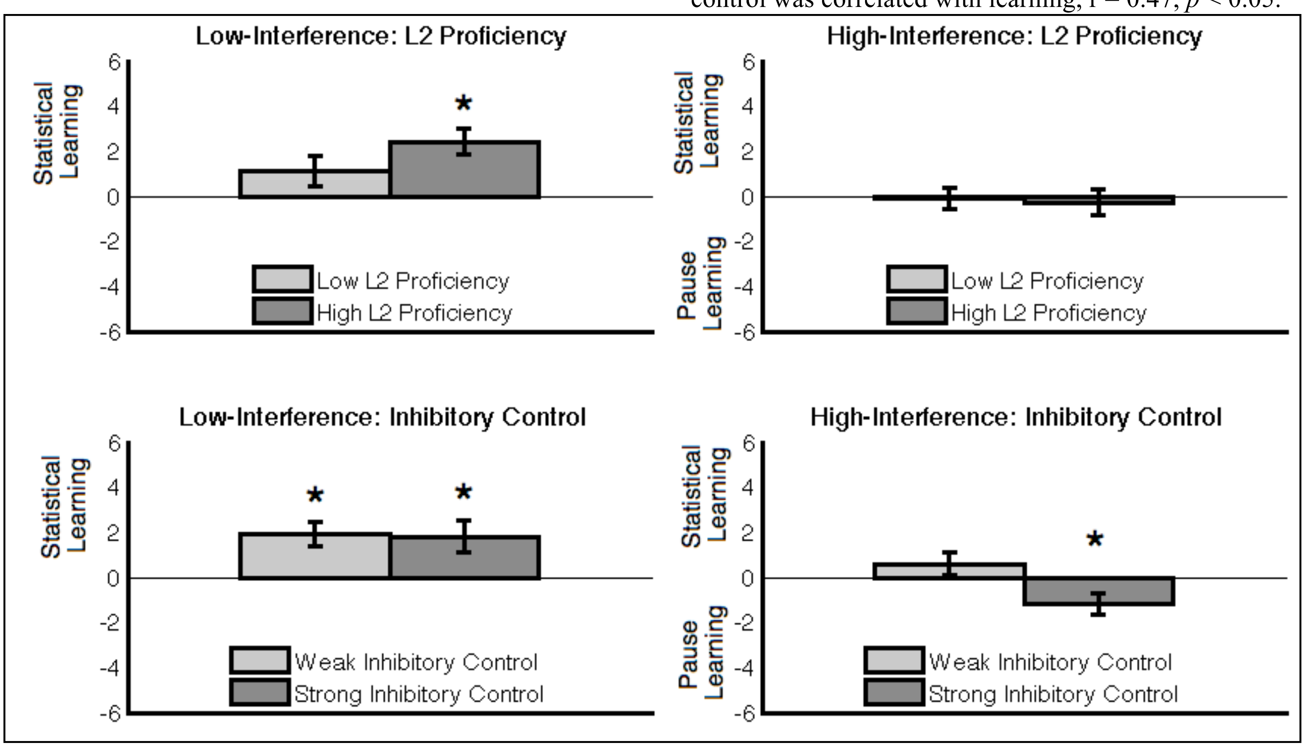

Figure 2: Effects of second language proficiency and inhibitory control on learning the new language. (Asterisks indicate a significant difference from chance, alpha of 0.05. Error bars indicate one standard error)

Discussion

In the present study, we found that bilingualism and inhibitory control can each contribute to novel language acquisition, depending on the level of interference present during learning. Specifically, when interference during training was low, high second language proficiency was associated with successful learning of words in the novel language, but inhibitory control ability did not discriminate between learners and non-learners—both groups showed acquisition of the novel language words. In contrast, when interference during training was high, strong inhibitory control was associated with successful acquisition, but second language proficiency did not affect learning—in this case, neither group was able to acquire the novel words. The results highlight the relative roles of previous language experience and inhibitory control on beginning language learning in different contexts.

Previous research has shown that bilinguals learn words in a novel language better than monolinguals (Cenoz, 2003; Cenoz & Valencia, 1994; Kaushanskaya & Marian, 2009b; Keshavarz & Astaneh, 2004; Sanz, 2000; Thomas, 1992; van Hell & Mahn, 1997). Here we suggest a possible mechanism for this advantage, in the form of improved word segmentation in a novel language by bilinguals. This ability to segment words from speech may depend in part on phonological working memory, which has previously been associated with improved statistical learning (Misyak & Christiansen, 2007). High proficiency in a second language has been associated with gains in phonological working memory (Majerus et al., 2008; Service et al., 2002), which may have contributed to bilinguals' ability to learn the words.

The failure of bilingualism to improve novel language learning in the high interference condition, though, suggests that second-language experience alone may not be sufficient to promote successful word segmentation in all learning contexts. Learning in the high-interference condition depended on inhibitory control ability; participants with strong inhibitory control learned words based on the pause lengths between letters, reflecting a strategy that minimized sources of interference. Recall that in the high-interference condition, the pauses conflicted with one source (transitional probabilities), while the transitional probabilities conflicted with two sources (pauses and previously learned words). The participants with strong inhibitory control may have been sensitive to this difference and applied inhibition most effectively, by suppressing all statistical cues and engaging learning of the pauses between words. While inhibitory control ability alone was sufficient to promote learning in a high-interference context, it may not be a good predictor of overall language learning ability. Inhibitory control did not discriminate learners and non-learners of the low-interference language, which had low inhibitory demands that both groups could conceivably manage. When there were few distractors in the signal, or between the signal and prior language knowledge, an increase in inhibitory control would not allow for increased information extraction from the signal.

Natural language learning is likely to benefit from both effects of second language proficiency and inhibitory control. When language interference occurs during learning it can disrupt acquisition, but bilinguals appear to be better able to manage this interference and have improved learning outcomes (Kaushanskaya & Marian, 2009a). One of the ways that interference during language learning can be managed is to globally suppress the native language (Levy, McVeigh, Marful, & Anderson, 2007; Linck, Kroll, & Sunderman, 2009). Bilinguals, though, appear to rely on facilitation of the newly-learned language to reduce interference (Bartolotti & Marian, 2010). These different patterns of controlling language interference reflect the development of the underlying control processes, which can influence learning success in difficult, high-interference contexts. By reducing interference, the saliency of novel words can be increased, and may be more readily acquired by bilinguals, who better remember novel words. Overall, our results demonstrate that novel language acquisition, a task that begins with the need to identify and remember new words, can benefit from linguistic experience and inhibitory ability. Prior experience acquiring words and an ability to attend to relevant cues can both improve learning, and may contribute to the bilingual advantage for novel language acquisition.

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