Published in final edited form as:

Memory. 2016 March ; 24(3): 409–422. doi:10.1080/09658211.2015.1013557.

Serial-Position Effects on a Free-Recall Task in Bilinguals

Jeewon Yoo and Margarita Kaushanskaya

University of Wisconsin-Madison

Abstract

In this study, we examined mechanisms that underlie free-recall performance in bilinguals' first language (L1) and second language (L2) through the prism of serial-position effects. On free-recall tasks, a typical pattern of performance follows a U-shaped serial-position curve, where items from the beginning of the list (the primacy effect) and items from the end of the list (the recency effect) are recalled with higher accuracy than items from the middle of the list. The present study contrasted serial-position effects on the free-recall task in Korean-English bilinguals' L1 vs. L2 and examined the relationship between an independent working memory (WM) measure and serial-position effects in bilinguals' two languages. Results revealed stronger pre-recency (primacy and middle) effects in L1 than in L2, but similar recency effects in the two languages. A close association was observed between WM and recall performance in the pre-recency region in the L1 but not in the L2. Together, these findings suggest that linguistic knowledge constrains free-recall performance in bilinguals, but only in the pre-recency region.

Keywords

bilingualism; free recall; primacy; recency

Short-term memory (STM) enables us to encode and retain information for a short period of time. The structure and the function of verbal short-term memory (STM) has been the focus of active and productive research over the past century (e.g., Baddeley, 2009; Gathercole, Willis, Emslie, & Baddeley, 1992; Baddeley, Thompson, & Buchanan, 1975; Cowan, et al., 1992; Miller, 1956). However, the vast majority of this work has focused on monolingual speakers. Although a number of studies have examined the role of verbal memory in second language acquisition (Baddeley, Gathercole, & Papagno, 1998; Cheung, 1996; Kormos, & Sáfár, 2008), relatively little is known about the actual underlying mechanisms of verbal short-term memory function in bilingual individuals. For example, one common measure of STM is a free word-recall task where participants listen to lists of words and are asked to recall as many of the words as possible in any order (e.g., Cowan et al., 1992). A classic finding is that performance on the free-recall task is characterized by a unique U-shaped serial-position curve, where items from the beginning of the list (the primacy effect) and items from the end of the list (the recency effect) are recalled with higher accuracy than items from the middle of the list (e.g., Davelaar et al., 2005; Glanzer & Cunitz, 1966). However, no previous study has examined whether such classic U-shaped effects can be

obtained in bilingual speakers, and whether these effects are rooted in the same fundamental mechanisms when examined in bilinguals' native vs. second language.

A traditional explanation of the U-shaped serial-position curve observed when performance on the free-recall task is plotted as a function of the location of the item on the list is the dual-component model of recall (e.g., Atkinson & Shiffrin, 1968; Glanzer, 1972; Glanzer & Cunitz, 1966). The dual-component model was proposed to suggest that two memory systems, short-term memory (STM) and long-term memory (LTM), were involved in performance on the free-recall task. The *primacy effects* on the free-recall task were interpreted to reflect the involvement of the LTM system in free-recall performance; that is, successful recall of the first few items on the list was attributed to the participants' ability to rehearse these items and to transfer them into the LTM (e.g., Rundus, 1971). The *recency effects* on the free-recall task were interpreted to reflect the involvement of the STM in free-recall performance; that is, successful recall of the last few items on the list was attributed to the participants' ability to store these items temporarily in the STM rather than in the LTM (e.g., Waugh & Norman, 1965).

Support for the dual nature of the free-recall task came from classic experiments where variables known to influence the LTM vs. the STM were pitted against each other (Craik & Levy, 1970; Glanzer & Cunitz, 1966; Murdock, 1962; Raymond, 1969; Shallice, 1975). For instance, Glanzer and Cunitz (1966) demonstrated that a faster presentation rate reduced recall performance for items in the pre-recency position (primacy and middle regions) but did not affect recall of items in the recency position of the serial-position curve. Conversely, the increased delay between the end of the list and recall reduced recall performance for items in the recency position while it did not affect the recall of items in the pre-recency position. Many subsequent studies supported the dissociation between the STM and the LTM in modulating performance on free-recall tasks by showing that variables known to influence LTM function, such as list length (e.g., Murdock, 1962), word frequency (e.g., Raymond, 1969) and semantic similarity (e.g., Craik & Levy, 1970) affected recall performance of items in the primacy position while variables known to influence STM function, such as phonological similarity (e.g., Shallice, 1975) affected recall performance of items in the recency position. More recently, the dual nature of the memory mechanisms supporting free-recall performance was instantiated in the context-activation model (e.g., Davelaar et al., 2005). This model suggests that two memory components are involved in free-recall performance: One is a changing context/episodic long-term memory system and the other is an activation-based short-term buffer.

However, a number of studies challenged this STM-LTM dissociation model for explaining the U-shaped effects in free-recall data (e.g., Baddeley & Hitch, 1974; Glenberg, 1984; Pinto & Baddeley, 1991). For instance, Pinto and Baddeley (1991) observed recency effects in their free-recall data when recall was tested after a significant delay – a finding that is at odds with the idea that recency effects arise within the STM system. To solve these problematic findings associated with recency data, unitary-component approaches of recall performance have been formulated. The basic premise of the unitary approaches is that the probability of recalling an item is proportional to the ratio of the inter-presentation interval (the interval between items) to the retention interval (the interval between the item and its

recall). Supporting this unitary component view, several alternative models have been suggested. For instance, the Temporal Context Model (TCM; Howard & Kahana, 1999) posits that words are associated with mathematically formulated temporal contexts, and words from the end of the list are recalled better because the context vector (in the just-presented item's representation) is used as a retrieval cue, with the ensuing recall advantage for the associated nearby items. Alternatively, the Scale-Invariant Memory, Perception, and Learning model (SIMPLE; Brown, Neath, & Chater, 2007) posits that items that are temporarily distinctive are advantaged at recall, and therefore, the last few items are recalled better because there are fewer interfering neighbors in the end of a list. Yet, just like dual-component models, single-component models do not fully explain the U-shaped serial-position curve associated with free-recall performance (for instance, the ratio rule cannot explain primacy effects) and the debates between the proponents of single-component models (e.g., Glenberg et al., 1980; Neath & Crowder, 1990) and dual-component models (e.g., Atkinson & Shiffrin, 1968; Davelaar et al., 2005; Glanzer, 1972; Gillund & Shiffrin, 1984) of free-recall performance continue.

The goal of the present study was not to differentiate between single- and dual-component models of free recall. Instead, we took the dual-component model as our starting theoretical point, because dual-component models explicitly posit influences from the LTM and the STM on free recall. This then makes them suitable to examining free recall performance in bilinguals, for whom the LTM and the STM influences on free recall may be more dissociable than in monolinguals. In cognitively-intact, adult speakers of a single language, the LTM and the STM systems function in tandem to support recall, such that is often difficult to dissociate performance patterns associated with LTM vs. STM. Examining free-recall performance in bilinguals may be useful not only because such examinations are woefully lacking in the literature, but also because LTM vs. STM influences on verbal recall may be more dissociable in bilingual speakers, especially when their performance in the native language is contrasted with their performance in the second language.

There is reason to hypothesize that serial-position effects on a free-recall task may be different in bilingual speakers' native vs. second language. Not surprisingly, a number of previous studies (e.g., Bialystok & Feng, 2009; Portocarrero, Burright, & Donovan, 2007) revealed that bilinguals tend to perform more successfully on language-based tasks in their native language (L1) vs. the second language (L2). Further, bilinguals also tend to perform better on verbal STM tasks when these are administered in their L1 vs. their L2 (e.g., Thorn & Gathercole, 1999). Such findings are interpreted as evidence for the link between long-term linguistic knowledge and STM function: That is, the more robust long-term linguistic knowledge associated with the L1 (vs. the L2) helps maintain the representations of L1 items (more so than of L2 items) presented on the STM task.

In the present study, we capitalized on prior literature indicating a link between bilinguals' LTM system and STM performance to examine the mechanisms that may underlie free recall in bilingual speakers. Specifically, we examined serial-position effects in L1 vs. L2 free-recall performance in late sequential bilingual speakers of Korean and English, who acquired their stronger native language, Korean, at birth, and who acquired their weaker second language, English, in their teens. The underlying hypothesis for this work was that if

the LTM system is involved in generating pre-recency effects on the free-recall task (in line with dual-component models), then pre-recency effects should be more robust in bilinguals' L1 – i.e., in the language that is stronger and more proficient – than in bilinguals' L2.

In order to even more precisely delineate the mechanisms that may underlie serial-position effects in bilinguals' free-recall performance, we also examined the associations between the pre-recency effect and the recency effect on the one hand, and an independent measure of working memory (WM) on the other hand, in bilinguals' L1 and L2. WM, unlike STM, involves the ability to store information for a brief period of time in the service of a cognitively-demanding task. A number of studies have documented a link between performance on free-recall tasks and performance on WM tasks (e.g., Unsworth, Brewer, & Spillers, 2011; Unsworth & Engle, 2007). For instance, Unsworth, Brewer, and Spillers (2011) found that individuals with high WM capacity utilized better strategic encoding processes (e.g., rehearsal, grouping, etc.) and more effective retrieval plans than individuals with low WM capacity on a cued recall task. In addition, Guida et al. (2013) found an interaction between serial-position effects on a free-recall task (pre-recency and recency) and WM span (high WM group and low WM group). Specifically, the difference in recall performance between the high WM group and the low WM group was present for the items in the pre-recency region (where presumably WM capacity could modulate LTM processes), but was reduced and non-significant for the items in the recency region (where presumably LTM processes could not modulate recall performance). In the present study, we relied on the association between WM capacity and LTM influences on pre-recency data established by previous studies to further test the possibility that LTM differently contributes to free-recall performance in the L1 vs. the L2. We hypothesized that the relationship between WM and recall performance in the pre-recency region would be stronger in the L1 than the L2 because bilinguals' LTM should be more stable in the L1 than the L2.

In summary, delineating the mechanisms of U-shaped effects in free-recall performance in terms of LTM vs. STM involvement has proven difficult due to the integrated nature of the two memory systems in monolingual speakers. Examining serial position effects in bilingual speakers' native vs. second language may yield a dissociation between the two memory systems. The goal of the present study was to examine free-recall performance in bilinguals' L1 vs. L2 as a function of serial-position effects.

Method

Participants

Twenty Korean-English bilinguals (*Mean Age* = 29.7, *SD* = 4.9; *Mean Years of Ed* = 19.8, *SD* = 3.7; *Mean Non-Verbal IQ* = 115.8, *SD* = 11.1) were recruited from the University of Wisconsin-Madison. All participants spoke Korean as their native language and acquired English as their second language in early teen years, with a mean acquisition age of 11.3 years (*SD* = 2.8). Detailed data were obtained regarding the participants' length of residence in Korea and the United States, the contexts in which they acquired Korean and English, and the contexts in which they were exposed to Korean and English at the time of the study levels (as reported on the *Language Experience and Proficiency Questionnaire, LEAP-Q*; Marian, Blumenfeld, & Kaushanskaya, 2007). Participants also completed standardized tests

of English vocabulary knowledge (*Peabody Picture Vocabulary Test – IV Mean* = 88.5, *SD* = 10.4; *Expressive Vocabulary Test Mean* = 97.1, *SD* = 13.2). Examination of self-reported data indicated that our participants were late, sequential bilingual speakers, whose self-reported language skills in Korean were more robust than their self-reported language skills in English. However, participants' knowledge of English was quite robust, as indicated both by their self-reports and by their performance on the standardized measures of English vocabulary knowledge. Specifically, self-reported speaking proficiency levels in English ranged between adequate and good, and scores on the vocabulary measures placed the participants firmly in the average performance range. See Table 1 for the participants' background characteristics.

Stimuli for the Working Memory Nonword Repetition (WM-NWR) Task in L1 and in L2

To measure participants' WM capacity, complex NWR tasks in both English and Korean were constructed, where participants were asked to repeat nonwords, while also completing a secondary animacy judgment task. For the English WM-NWR task, 48 English nonwords were selected from Gupta et al. (2004) corpus. Of these, 16 were 2-syllable nonwords, 16 were 4-syllable nonwords, and 16 were 6-syllable nonwords. For the Korean WM-NWR task, 48 Korean nonwords were created, following phonologically plausible syllables in Korean (Lee, 2006). For a secondary judgment task, 48 nouns were selected in each language, with half of the nouns being animate and half of the nouns being inanimate. The nonword stimuli followed language-specific phonotactics, such that English nonwords followed English phonotactics while Korean nonwords followed Korean phonotactics. The nonwords across two languages were matched on acoustic duration.

Stimuli for the Free-Recall Task in L1 and in L2

One hundred and thirty five English nouns were selected. The nouns were 1, 2, and 3 syllables in length, grouped into lists of 10, 15, and 20 words. There were three 10-word lists, three 15-word lists, and three 20-word lists for each syllable-length. Across lists and syllables, nouns were matched on lexical frequency (Brysbaert & New, 2009) and on concreteness (MRC Psycholinguistic Database). One hundred and thirty five Korean nouns were selected and grouped based on the same criteria as the English nouns. Across lists and syllables, Korean nouns were matched on lexical frequency (the National Institute of the Korean Language's 2003 Modern Korean Usage Frequency Survey) and on concreteness (based on their English translations). See Appendixes 1 and 2 for English and Korean words lists. The English nouns were recorded by a female native speaker of English while the Korean nouns were recorded by a female native speaker of Korean. Task parameters were matched for the English and the Korean word-recall tasks, and speed of presentation was controlled across list lengths within each syllable length, with the average speed of 1.1 words/sec.

Procedure

All participants completed the free-recall tasks and the WM-NWR tasks in both languages during different sessions, and the procedure for each task was identical for both languages. Participants completed the Korean tasks first and completed the English tasks a week later.

This order of sessions was fixed because the English tasks were more taxing for the participants than the Korean tasks. In order to avoid attrition, it was decided to maintain the order across participants, with Korean always being the language of the first session. The instructions were always administered in Korean (across both sessions) to ensure understanding.

For the WM-NWR task, the 2-syllable nonwords were presented first, followed by 4-syllable nonwords, and 6-syllable nonwords. The order of nonwords at each syllable length was randomized for each participant. Each participant heard a nonword first, followed by the noun (animate/ inanimate), and was asked to judge the animacy of each noun by pressing “/” for an animate noun, and “z” for an inanimate noun. The participant then repeated the nonword as accurately as possible after a cue. The time between the presentation of the nonword and the cue to repeat it was set to 4000 msec. Each participant’s productions were recorded and coded off-line.

For the free-recall task, each participant heard 1-syllable words in 10-word, 15-word, and 20-word lists; followed by 2-syllable words in 10-word, 15-word, and 20-word lists; etc. The order of words in each list was randomized for each participant. After listening to each list of words, participants were cued to recall as many words as possible regardless of their order. Each participant’s productions were recorded and coded off-line.

All participants were administered two English vocabulary measures, the *Peabody Picture Vocabulary Test (PPVT-III)*, Dunn & Dunn, 1997) and the *Expressive Vocabulary Test (EVT)*, William, 1997), as well as the non-verbal IQ measure, the Visual Matrixes subtest of the *Kaufman Brief Intelligence Test (KBIT-2)*, Kaufman, & Kaufman, 2004). Finally, all participants were asked to complete the *LEAP-Q* (Marian, Blumenfeld, & Kaushanskaya, 2007) to elicit data regarding their language background.

Coding and analyses

Coding was done by a native speaker of English for English tasks and a native speaker of Korean for Korean tasks. For the WM-NWR task, proportion correct score was obtained for each nonword by calculating the proportion of correctly recalled phonemes out of total number of phonemes per nonword. Phonemes correct rather than syllables or nonwords correct was used because the nonword repetition task was quite difficult, and more global measures of accuracy may have underestimated participants’ levels of performance. A similar approach to coding nonword repetition data was used by other studies (e.g., Dollaghan & Campbell, 1998; Moore, Tompkins, & Dollaghan, 2010). Data were collapsed across syllable lengths to obtain a measure of verbal working memory capacity in each language.

For the free-recall task, all productions were transcribed word-for-word and coded for correctness. Omissions, semantic associates, and duplications were scored as incorrect. Initially, each list was divided into three regions: Primacy, middle, and recency. The visual representation of bilinguals’ free-recall performance in the L1 vs. the L2 can be found in Figure 1. Performance in each language clearly followed the traditional U-shaped serial-position curve. However, in order to boost power and to reduce the number of follow-up

comparisons, primacy and middle region data were collapsed to yield pre-recency region data. This approach is in line with prior studies where pre-recency and recency effects (rather than primacy and recency effects) were contrasted (Guida et al., 2013). Each list was thus divided into the pre-recency region and the recency region. Specifically, for 10-word lists, the first 7 words were denoted as the pre-recency region, and the last 3 words were denoted as the recency region. For 15-word lists, the first 10 words were denoted as the pre-recency region and the last 5 words were denoted as the recency region. Finally, for 20-word lists, the first 13 words were denoted as the pre-recency region and the last 7 words were denoted as the recency region. The proportion correct scores were obtained for each region in each list. Data were collapsed across lists and syllable lengths to boost power.

Three types of analyses were conducted. First, to compare WM capacity between bilinguals' two languages, a paired-samples *t*-test comparing bilinguals' performance in English vs. Korean on the WM-NWR task was conducted. Second, to examine whether there was an effect of language (L1/L2), position (pre-recency/recency), and list length (10/15/20-word list) on free-recall performance, a $2 \times 2 \times 3$ repeated-measures ANOVA was conducted. Lastly, correlation analyses were conducted to test the relationship between WM capacity and free-recall performance in each position, within each language.

Results

WM-NWR performance in bilinguals' L1 vs. L2

A comparison between bilinguals' performance on the WM-NWR task in English vs. Korean revealed a significant difference between bilinguals' two languages, $t(19) = 9.32$, $p < 0.001$; participants performed better on this WM-NWR task in their L1 ($M = 0.89$, $SD = 0.04$) than their L2 ($M = 0.76$, $SD = 0.08$). Similarly, for the secondary animacy judgment task in English vs. Korean, participants performed better in their L1 ($M = 0.96$, $SD = 0.04$) than in their L2 ($M = 0.84$, $SD = 0.08$), $t(19) = 6.94$, $p < 0.001$.

Bilinguals' free-recall performance in L1 vs. L2

The repeated-measures ANOVA yielded a main effect of position, $F(1, 19) = 65.01$, $p < 0.001$, $\eta_p^2 = 0.77$, a main effect of list length, $F(1, 19) = 145.03$, $p < 0.001$, $\eta_p^2 = 0.88$, a 2-way interaction between language and position, $F(1, 19) = 11.74$, $p < 0.001$, $\eta_p^2 = 0.38$, and a 3-way interaction between language, position, and list, $F(2, 38) = 10.69$, $p < 0.001$, $\eta_p^2 = 0.36$. Participants recalled more words in the recency regions ($M = 0.56$, $SE = 0.02$) than in the pre-recency region ($M = 0.28$, $SE = 0.02$), $p < 0.001$, and more words in 10-word list ($M = 0.53$, $SE = 0.01$) than 15-word lists ($M = 0.40$, $SE = 0.01$), $p < 0.001$ and in 15-word lists than in 20-word lists ($M = 0.33$, $SE = 0.01$), $p < 0.001$.

To identify the locus of the interaction between position and language, follow-up comparisons were conducted. Pair-wise comparisons between positions (collapsed across list lengths) within each language revealed that there were significant differences in recall performance between the pre-recency region and the recency region both in the L1, $t(19) = -5.36$, $p < 0.001$ and in the L2, $t(19) = -8.70$, $p < 0.001$. Pair-wise comparisons between each language for each position revealed that bilinguals recalled significantly more words in

the pre-recency region ($t(19) = 4.58, p < 0.001$) when they used their L1 ($M = 0.33, SD = 0.09$) than when they used their L2 ($M = 0.24, SD = 0.10$). However, there was no difference between L1 ($M = 0.53, SD = 0.11$) and L2 recall ($M = 0.58, SD = 0.12$) for the items in the recency region ($t(19) = -1.37, p = 0.19$). See Figure 2 for the visual representation of these data.

Follow-up comparisons for the 3-way interaction examined differences between position effects (pre-recency vs. recency) at each list length for each language, as well as differences between languages (L1 vs. L2) at each position for each list length. Paired sample *t*-tests between pre-recency and recency data at each list length for each language revealed that in the L1, there was no significant difference in recall performance between pre-recency and recency regions for 10-word lists, $t(19) = -1.23, p = 0.23$. However, bilinguals recalled significantly more words in the recency region than in pre-recency region for 15-word lists, $t(19) = -4.77, p < 0.001$, and 20-word lists, $t(19) = -9.59, p < 0.001$. In the L2, bilinguals recalled significantly more words in the recency region than in pre-recency region across all list lengths, including 10-word lists, $t(19) = -6.46, p < 0.001$, 15-word lists, $t(19) = -7.47, p < 0.001$, and 20-word lists, $t(19) = -6.42, p < 0.001$. Paired sample *t*-tests between L1 and L2 at each position for each list length (see Figure 3) revealed that for 10-word lists, bilinguals recalled more words in the L1 than in the L2 in pre-recency region, $t(19) = 7.41, p < 0.001$, but not the recency region, $t(19) = -1.82, p = 0.09$. Similarly, for 15-word lists, bilinguals recalled more words in the L1 than in the L2 in pre-recency region, $t(19) = 2.07, p = 0.05$, but not the recency region, $t(19) = -1.70, p = 0.11$. However, for 20-word lists, bilinguals recalled more words in the L1 than in the L2 in the recency region, $t(19) = 2.43, p < 0.05$, but there was no difference in recall performance between the L1 and the L2 in pre-recency region, $t(19) = 0.25, p = 0.80$.

Correlations

In the L1, there was a significant relationship between WM capacity and free recall in the pre-recency region ($r = 0.53, p < 0.05$), such that higher WM capacity was associated with higher recall of words in the pre-recency region. However, there was no relationship between WM capacity and free recall in the recency region ($r = -0.18, p = 0.46$). In the L2, there was no relationship between WM capacity and free-recall performance either in the pre-recency region ($r = -0.06, p = 0.81$) or the recency region ($r = 0.37, p = 0.11$).

Discussion

The purpose of the current study was to examine whether (1) bilinguals' encoding and retrieval patterns on the free-recall task would be shaped by different levels of linguistic knowledge, as instantiated by the differences between bilinguals' L1 and L2, and (2) whether recall performance from the different regions of the lists would be differentially related to WM capacity. We found that some aspects of free-recall performance in bilinguals are similar across the L1 and the L2. Bilinguals' performance on a free-recall task followed the typical U-shaped serial-position curve both in the L1 and the L2. Furthermore, bilinguals showed better performance when recalling items from the recency regions than from pre-recency regions both in the L1 and the L2, suggesting that in general, bilinguals in this study

adopted a global recency recall strategy. Finally, bilinguals demonstrated list-length effects in both the L1 and the L2, such that free recall of shorter lists was more successful than of longer lists (consistent with Baddeley et al., 1975; LaPointe & Engle, 1990; Lovatt, Avons, & Masterson, 2000). However, we also observed distinct patterns of free-recall performance in the L1 and the L2, suggesting an effect of language experience on the mechanisms that underlie free-recall performance in bilinguals.

Bilinguals' performance on the free-recall task was characterized by a stronger pre-recency effect in the L1 than in the L2. Bilinguals in our study were late, sequential bilinguals with stronger language skills (as indexed by broad self-ratings of proficiency speaking, understanding, and reading) in their L1 (Korean) than in their L2 (English). According to the dual-component model of U-shaped free-recall performance, pre-recency effects are considered to be rooted in the LTM system (e.g., Murdock, 1962; Raymond, 1969), and stronger pre-recency effects in the L1 than in the L2 observed in the present study are consistent with this view. That is, it appears that bilinguals were better able to take advantage of their linguistic knowledge (LTM) to scaffold free recall in their L1. Since bilinguals tested here were more proficient in their L1 than their L2, it is likely that they were able to rehearse the first items on the list more effectively when the task was conducted in the L1, their more proficient language, than in the L2, their less proficient language. This finding is also in line with the more recent context-activation model of free recall (e.g., Davelaar et al., 2005) that construes primacy effects to be the result of an interaction between a dynamic activation buffer that stores phonological and semantic information and selective updating supported by the attentional control system. Therefore, bilinguals' stronger pre-recency effects in the L1 may be interpreted to suggest that bilinguals can selectively update and activate items from the beginning of the list in a buffer system more effectively in the L1 than in the L2 because of the more robust semantic and phonological knowledge associated with the native language.

In contrast to the language effects in the pre-recency region, bilinguals in the present study recalled items from the recency regions equally well in the L1 and the L2. That is, bilinguals were able to maintain and retrieve items from the ends of the lists in their weaker language as efficiently as they did in their native language. However, this finding is qualified by the fact that we observed a three-way interaction among language, list length, and position effects. This interaction appears to be driven by two patterns of results. First, the position effect (i.e., better recall in the recency than the pre-recency region) was observed across all list lengths in the L2 but only for the longer lists (15- and 20-word lists) in the L1. Previous studies have also reported list-length effects in serial position curves, such that primacy effects are dominant for shorter lists (i.e., 3–4 word lists) while recency effects are dominant for longer lists (e.g., Ward, Tan, & Grenfell-Essam, 2010). The broad recency effects observed in our data across list lengths is likely due to the fact that in our study, shorter lists (10-word lists) may in fact exceed the length of lists that yields dominant primacy effects. The finding that the recency effect was not significant for 10-word lists in the L1 indicates that 10-word lists operated as “shorter lists” in the bilinguals' native language and as “longer lists” in the bilinguals' second language.

Second, the native-language recall advantage was observed in the pre-recency region for shorter lists (10- and 15-word lists) but in the recency region for the longest list (20-word list). This therefore accounts for the broad finding of L1 advantages in the pre-recency but not the recency region, since the recency effect in the L1 for 20-word lists was washed out by non-significant recency effects in the L2 for 10- and 15-word lists. List-length effects in recall tasks may reflect involvement of different processes, such that performance on longer lists shares a great deal of variance with performance on complex span task, while performance on shorter lists does not (Unsworth & Engle, 2006). That is, recall of longer lists (but not shorter lists) likely involves reliance on focus-of-attention mechanisms (Cowan, 2001). We observed an L1 recall advantage for shorter list lengths in the pre-recency region likely because the robust L1 knowledge in the LTM enabled participants to rehearse the first few items on these shorter lists more efficiently in the L1. Conversely, we observed an L1 recall advantage for longer lists in the recency region likely because longer lists demanded recruitment of additional attentional resources, and these resources were utilized more efficiently in the L1 than in the L2. An alternative (or an additional) possibility is that redintegration processes acted upon recall performance for the longer lists but not the shorter lists, with more effective redintegration occurring in the L1. Redintegration is posited to underlie the ability to reconstruct incomplete language representation from the memory trace when retrieving verbal materials from the STM (e.g., Hulme et al., 1997; Schweickert, 1993). When the temporal capacity of the STM exceeds the limit for longer lists, the items stored in the LTM are replaced by newly entered items from the STM. It may be that the redintegration process is more active for longer lists in the L1 than in the L2 because the LTM is more robust and stable in the L1. The reconstruction process in the L1 may therefore be more efficient than in L2, resulting in L1 recall advantages for longer list.

While it is difficult to pinpoint the exact mechanisms that underlie the interactions among language, list-length, and serial-position effects in our data, it is clear that serial recall in bilinguals is a highly dynamic system, characterized by complex relationships between linguistic knowledge and basic parameters of free recall. Our findings both converge and diverge with the previous data regarding LTM influences on serial recall, likely because previous studies have not dissociated pre-recency and recency effects (Thorn & Gathercole, 1999; Thorn, Gathercole, & Frankish, 2002). The finding that there were clear L1 recall advantages in the pre-recency region converge with previous studies of L1 advantages, and reiterate the involvement of the LTM in recall performance, with stronger L1 facilitating recall. The finding that there were no L1 advantages in the recency region diverge from previous studies of L1 advantages, and indicate that other cognitive processes (i.e., the focus of attention) can overtake L1 influences on STM, especially for longer list lengths (Unsworth & Engle, 2006). By considering the STM system in a more nuanced way, and by zeroing in on serial-position effects in free-recall performance, here we observe that *pre-recency* effects in free recall (which are likely influenced by the LTM system more than recency effects) are constrained by linguistic knowledge.

Correlation analyses used to examine the relationship between recall performance and WM capacity revealed that cognitive processes that underlie bilingual recall may differ across L1 and L2, especially for sequential bilinguals whose L2 was acquired later in life. The positive

correlation obtained between WM capacity and *pre-recency* effects is consistent with previous studies suggesting that high WM capacity is linked to better strategic memory retrieval (e.g., Unsworth, Brewer, and Spillers, 2011), especially of the items from the pre-recency regions (e.g., Guida et al., 2013). However, finding such a relationship only in the L1 but not in the L2 indicates that the ability to draw upon the WM system to support free recall is less viable in the context of a relatively weak linguistic knowledge base associated with the L2.

One caveat to this interpretation is that the current study cannot dissociate the effects of L1 vs. L2 on free recall from language-specific effects. That is, it may be that these findings characterize free recall in Korean vs. English rather than free recall in the native vs. the second language. In an effort to inform this issue, we analyzed pilot data collected for this study from 19 monolingual speakers of English. Because the goal of the study was not to compare monolingual and bilingual free-recall performance, this group of monolingual participants did not match the bilingual group in demographic characteristics (*Mean Age* = 24.73; *Mean Years of Education* = 15.89; *Mean Non-Verbal IQ* = 105.87). However, we conducted correlation analyses between the monolinguals' WM data and free-recall data in order to examine whether the pattern would be similar to the pattern observed for bilinguals' L1 (Korean) or L2 (English). The logic was that if the pattern of results observed for the bilingual participants is reflective of native- vs. second-language dynamics, the monolingual data would resemble bilingual L1 data. Conversely, if the pattern of results observed for bilingual participants is reflective of Korean vs. English differences, the monolingual data would resemble bilingual L2 data. When correlation analyses were conducted between monolinguals' performance on the WM-NWR task and the free-recall task, we found a significant relationship between WM capacity and free recall in the pre-recency region ($r = 0.5, p < 0.05$), but not in the recency region ($r = -0.23, p = 0.34$). These findings mirror precisely the pattern of results observed for the Korean data in bilinguals. This indicates that our findings for Korean-English bilinguals reflect native-language vs. second-language dynamics characterizing free recall, rather than the language-specific factors associated with Korean vs. English.

The present findings have implications for models of free recall, whose interpretation and validation have proven difficult because of the integrated nature of memory systems in cognitively-intact monolingual speakers. By investigating bilinguals' performance on the free-recall task, we can begin to disentangle the (possibly) distinctive contributions of the LTM and the STM to free recall because bilinguals, especially bilinguals like those studied here, have distinct levels of knowledge (i.e., LTM) associated with their native language vs. their second language. Although single-component models (e.g., Baddeley, 1986; Neath & Crowder, 1990) can readily account for comparable recency effects in L1 and L2 free-recall performance, they cannot easily account for the distinctive patterns of pre-recency effects in bilinguals' two languages observed here. The goal for the future studies would be to examine whether the pattern of results for L1 vs. L2 observed here is specific to late, sequential bilinguals, with more proficient levels of native-language vs. second-language knowledge, or whether it would generalize to other bilingual populations, including those who acquired their two languages simultaneous, and those with balanced levels of L1/L2

proficiency. Further, future studies should incorporate objective measures of linguistic knowledge in bilinguals' two languages, and include tests of specific linguistic domains (e.g., phonology, vocabulary, syntax) in order to delineate which aspects of linguistic knowledge constrain STM performance. In the current study, the administration of standardized vocabulary measures in English served to establish fairly strong levels of English vocabulary skills in our bilingual participants. However, it would have been useful to also gain an understanding of how participants' English vocabulary skills compare with their Korean vocabulary skills to corroborate the self-reported data. Finally, future work should fully counterbalance the order and language of the tasks. In the current study, the English and the Korean sessions occurred on different days, a week apart, thus the consistent order of testing (Korean first) was unlikely to influence the results since order effects typically guarded against by counterbalancing (i.e., fatigue) would be unlikely.

In conclusion, the findings of the present study revealed distinctive patterns of recall in bilinguals' two languages that are generally congruent with the dual-component model of free recall (e.g., Craik & Levy, 1970; Davelaar et al., 2005; Murdock, 1962; Shallice, 1975). Stronger pre-recency effects in the L1 than the L2 suggest that the LTM (presumably the locus of linguistic knowledge) plays a crucial role in the ability to adopt active encoding and retrieval strategies when recalling items from the beginning of the lists. Further, bilinguals' WM capacity is closely related to recalling items in the pre-recency region in the L1 but not the L2, suggesting that dynamic interactions between the LTM and the STM that characterize free-recall performance in bilinguals are crucially dependent on bilinguals' knowledge of their two languages.

Acknowledgments

This research was supported by NIDCD Grants R03 DC010465 and R01 DC011750 to Margarita Kaushanskaya. The authors are grateful to Stephanie Van Hecke, Jenna Osowski, Julie Winer, and Marissa Stern for help with data collection and data coding.

References

- Atkinson, RC.; Shiffrin, RM. Human memory: A proposed system and its control processes. In: Spence, KW.; Spence, JT., editors. *The psychology of learning and motivation*. Vol. 2. New York, NY: Academic Press; 1968. p. 89-195.
- Baddeley, AD. *Working memory*. Oxford, England: Oxford University Press; 1986.
- Baddeley, AD. Short-term memory. In: Baddeley, AD.; Eysenck, MW.; Anderson, MC., editors. *Memory*. Hove: Psychology Press; 2009. p. 19-40.
- Baddeley AD, Gathercole S, Pappagno C. The phonological loop as a language learning device. *The Psychological Review*. 1998; 105:158–173. [PubMed: 9450375]
- Baddeley, AD.; Hitch, GJ. Working memory. In: Bower, GH., editor. *The psychology of learning and motivation: Vol. 6. Advances in research and theory*. New York: Academic Press; 1974. p. 47-90.
- Baddeley AD, Thompson N, Buchanan M. Word Length and the Structure of Memory. *Journal of Verbal Learning and Verbal Behaviour*, I. 1975:575–589.
- Bialystok E, Feng X. Language proficiency and executive control in proactive interference: Evidence from monolingual and bilingual children and adults. *Brain & Language*. 2009; 109:93–100. [PubMed: 18834625]
- Brown GDA, Neath I, Chater N. A temporal ratio model of memory. *Psychological Review*. 2007; 114:539–576. [PubMed: 17638496]

- Brysbaert M, New B. Moving beyond Kucera and Francis: A critical evaluation of current word frequency norms and the introduction of a new and improved word frequency measure for American English. *Behavior Research Methods*. 2009; 41:977–990. [PubMed: 19897807]
- Cheung H. Nonword span as a unique predictor of second-language vocabulary learning. *Developmental Psychology*. 1996; 32(5):867–873.
- Cowan N. The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences*. 2001; 24:87–114. [PubMed: 11515286]
- Cowan N, Day L, Saultus JS, Keller TA, Johnson T, Flores L. The role of verbal output time in effects of word length on immediate memory. *Journal of Memory and Language*. 1992; 31:1–17.
- Craik FIM, Levy BA. Semantic and acoustic information in primary memory. *Journal of Experimental Psychology*. 1970; 86:77–82.
- Davelaar EJ, Goshen-Gottstein Y, Ashkenazi A, Haarmann HJ, Usher M. The demise of short-term memory revisited: Empirical and computational investigations of recency effects. *Psychological Review*. 2005; 112:3–42. [PubMed: 15631586]
- Dollaghan C, Campbell T. Nonword repetition and child language impairment. *Journal of Speech, Language, and Hearing Research*. 1998; 41:1136–1146.
- Dunn, LM.; Dunn, LM. Peabody Picture Vocabulary Test. 3rd ed.. Circle Pines, MN: American Guidance Service; 1997.
- Gathercole SE, Willis C, Emslie H, Baddeley A. Phonological memory and vocabulary development during the early school years: A longitudinal study. *Developmental Psychology*. 1992; 28(5):887–898.
- Gillund G, Shiffrin RM. A retrieval model for both recognition and recall. *Psychological Review*. 1984; 91:1–67. [PubMed: 6571421]
- Glanzer, M. Storage mechanisms in recall. In: Bower, GH.; Spence, JT., editors. *The psychology of learning and motivation*. New York: Academic Press; 1972. p. 129-193.
- Glanzer M, Cunitz A. Two storage mechanisms in free recall. *Journal of Verbal Learning and Verbal Behavior*. 1966; 5:351–360.
- Glenberg AM. A retrieval account of the long-term modality effect. *Journal of Experimental Psychology: Learning, Memory, & Cognition*. 1984; 10:16–31.
- Glenberg AM, Bradley MM, Stevenson JA, Kraus TA, Tkachuk MJ, Gretz AL. A two-process account of long-term serial position effects. *Journal of Experimental Psychology: Human Learning and Memory*. 1980; 6:355–369.
- Guida A, Gras D, Noel Y, Le Bohec O, Quaireau C, Nicolas S. The effect of long-term working memory through personalization applied to free recall: uncurbing the primacy effect enthusiasm. *Memory and Cognition*. 2013; 41:571–587. [PubMed: 23297048]
- Gupta P, Lipinski J, Abbs B, Lin P-H, Aktunc ME, Ludden D, Martin N, Newman R. Space Aliens and Nonwords: Stimuli for Investigating the Learning of Novel Word-Meaning Pairs. *Behavioral Research Methods, Instruments, and Computers*. 2004; 36:699–703.
- Howard MW, Kahana MJ. Contextual variability and serial position effects in free recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 1999; 25:923–941.
- Hulme C, Roodenrys S, Schweickert R, Brown GDA, Martin S, Stuart G. Word-frequency effects on short-term memory tasks: Evidence for a reintegration process in immediate serial recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 1997; 23:1217–1232.
- Kaufman, AS.; Kaufman, NL. Kaufman Brief Intelligence Test. 2nd ed. Bloomington, MN: Pearson, Inc.; 2004.
- Kormos J, Sáfár A. Phonological short term-memory, working memory and foreign language performance in intensive language learning. *Bilingualism: Language and Cognition*. 2008; 11(2): 261–271.
- LaPointe LB, Engle RW. Simple and complex word spans as measures of working memory capacity. *Journal of Experimental Psychology: Learning, Memory and Cognition*. 1990; 16:1118–1133.
- Lee, JW. Master's thesis. Korea: Korea Nazarene University; 2006. Effects of combined word recognition and reading comprehension intervention on reading pseudowords for school-aged children with reading disabilities.

- Lovatt P, Avons SE, Masterson J. The word-length effect and disyllabic words. *Quarterly Journal of Experimental Psychology*. 2000; 53A:1–22. [PubMed: 10718061]
- Marian V, Blumenfeld HK, Kaushanskaya M. The Language Experience and Proficiency Questionnaire (LEAP-Q): Assessing language profiles in bilinguals and multilinguals. *Journal of Speech, Language, and Hearing Research*. 2007; 50:940–967.
- Miller GA. The magical number seven, plus or minus two: Some limits to our capacity for processing information. *Psychological Review*. 1956; 63:81–97. [PubMed: 13310704]
- Moore M, Tompkins C, Dollaghan C. Manipulating articulatory demands in non-word repetition: A 'late-8' non-word repetition task. *Clinical Linguistics & Phonetics*. 2010; 24(12):997–1008. [PubMed: 20887214]
- Murdock BB. The serial position effect of free recall. *Journal of Experimental Psychology*. 1962; 64:482–488.
- Neath I, Crowder RG. Schedules of presentation and temporal distinctiveness in human memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 1990; 16:316–327.
- Pinto A, Da C, Baddeley AD. Where did you park your car? Analysis of a naturalistic long-term recency effect. *European Journal of Cognitive Psychology*. 1991; 3:297–313.
- Portocarrero JS, Burright RG, Donovick PJ. Vocabulary and verbal fluency of bilingual and monolingual college students. *Archives of Clinical Neuropsychology*. 2007; 22:415–422. [PubMed: 17336036]
- Raymond BJ. Short-term storage and long-term storage in free recall. *Journal of Verbal Learning and Verbal Behavior*. 1969; 8:567–574.
- Rundus D. Analysis of rehearsal processes in free recall. *Journal of Experimental Psychology*. 1971; 89:63–77.
- Schweickert R. A multinomial processing tree model for degradation and redintegration in immediate recall. *Memory & Cognition*. 1993; 21:168–175. [PubMed: 8469125]
- Shallice, T. On the contents of primary memory. In: Rabbitt, PMA.; Dornic, S., editors. *Attention and performance V*. London: Academic Press; 1975. p. 269–280.
- The National Institute of the Korean Language. Modern Korean Usage Frequency Survey [data file]. 2010 Available from <http://www.korean.go.kr/>.
- Thorn ASC, Gathercole SE. Language-specific knowledge and short-term memory in bilingual and non-bilingual children. *Quarterly Journal of Experimental Psychology*. 1999; 52A:303–324. [PubMed: 10371873]
- Thorn ASC, Gathercole SE, Frankish CR. Language familiarity effects in short-term memory: The role of output delay and long-term knowledge. *Quarterly Journal of Experimental Psychology*. 2002; 55A:1363–1383. [PubMed: 12420999]
- Unsworth N, Brewer GA, Spillers GJ. Inter- and intra-individual variation in immediate free recall: An examination of serial position functions and recall initiation strategies. *Memory*. 2011; 19(1):67–82. [PubMed: 21240749]
- Unsworth N, Engle RW. Simple and complex memory spans and their relation to fluid abilities: Evidence from list-length effects. *Journal of Memory and Language*. 2006; 54:68–80.
- Unsworth N, Engle RW. The nature of individual differences in working memory capacity: Active maintenance in primary memory and controlled search from secondary memory. *Psychological Review*. 2007; 114:104–132. [PubMed: 17227183]
- Waugh NC, Norman DA. Primary memory. *Psychological Review*. 1965; 72:89–104. [PubMed: 14282677]
- William, KT. Expressive Vocabulary Test. Circle Pines, MN: American Guidance Service; 1997.
- Wilson MD. The MRC Psycholinguistic Database: Machine Readable Dictionary, Version 2. *Behavioural Research Methods, Instruments and Computers*. 1988; 20(1):6–11.

Appendix 1

English Words List (1-Syllable, 2-Syllable and 3-Syllable Words)

	1-Syllable Words	2-Syllable Words	3-Syllable Words
10-Word Lists	FAN	ANTIQUE	CANDIDATE
	POLE	OUTFIT	CIGARETTE
	LUMP	GRAVEL	ENGINEER
	CROW	CHINA	GRANDMOTHER
	RAY	VOTER	INSTRUMENT
	SHOT	PAINTING	MONUMENT
	TUBE	MUSCLE	OPENING
	BELT	SINGER	PHOTOGRAPH
	EAR	FILLING	TREASURER
	WINE	LADY	VEHICLE
15-Word Lists	BEAM	AXLE	AVENUE
	CROSS	BOTTLE	BEVERAGE
	DOG	CANAL	CONVENTION
	FLAG	CEILING	FURNITURE
	GOWN	DIAMOND	ELEPHANT
	HAIR	FABRIC	GRADUATE
	INCH	GARBAGE	HONEYMOON
	LAWN	GIANT	INSTITUTE
	MOTH	JACKET	MUSICIAN
	PRINCE	MASTER	OFFICER
	RUST	NATIVE	PINEAPPLE
	STONE	OVEN	RADIO
	TEAR	POET	REGISTER
20-Word Lists	THORN	ENTRANCE	SALARY
	YACHT	TRACTOR	TELESCOPE
	ASH	ANGLE	APARTMENT
	BRICK	BARREL	BACTERIA
	EGG	COFFIN	CAMERA
	CHAIN	DISEASE	CHOCOLATE
	COACH	ESSAY	DETECTIVE
	DRILL	FOREST	ENVELOPE
	FAN	HOUSEHOLD	FOREIGNER
	GRASS	JURY	GALLERY
	HORN	LOBSTER	GENTLEMAN
	ISLE	MOVIE	IVORY
	JUDGE	ONION	LIBRARY
	KNIFE	PIGEON	MEDICINE
	LAKE	RABBI	NEWSPAPER
	MOLD	SHOULDER	ORCHESTRA
	SHEEP	SIGNAL	PROFESSOR

1-Syllable Words	2-Syllable Words	3-Syllable Words
PATH	TIRE	RECITAL
RIB	VILLAGE	SUBMARINE
SPADE	WALNUT	TELEPHONE
TRAIN	WEDDING	UNIFORM
VEST	YELLOW	VOLCANO

Appendix 2

Korean Words List (1-Syllable, 2-Syllable and 3-Syllable Words)

	1-Syllable Words		2-Syllable Words		3-Syllable Words	
	Korean	Translation	Korean	Translation	Korean	Translation
10-Word Lists	dol	stone	eui ja	chair	a jeo ssi	uncle
	chum	dance	doong ji	nest	whae gook in	foreigner
	heuk	soil	mac joo	beer	wha jang sil	toilet
	jang	market	ja nyeo	children	dung o ri	lump
	geot	surface	sim jang	heart	gwan gwang gaek	tourist
	si	city	yang pa	onion	bal geol um	step
	mal	horse	hyung sa	detective	po do joo	wine
	beol	bee	ba wui	rock	jeo go ri	coat
	bbiyam	cheek	cho won	prairie	na moot eep	leaf
	yeol	heat	geun yook	muscle	mo toong ee	corner
15-Word Lists	hack	core	chak sang	desk	hal meo ni	grandmother
	dak	chicken	chim dae	bed	go yang ee	cat
	bbang	bread	tong joong	pain	so na moo	pine
	kal	knife	gyeo ja	mustard	gyung gee jang	stadium
	hyeo	tongue	hyun geum	cash	pa chool so	police substation
	gook	soup	ba nul	needle	jung chi in	politician
	so	cow	saeng sun	fish	jee bae ja	ruler
	jeol	temple	mi so	smile	noon dong ja	pupil
	ee	tooth	sa gwa	apple	bal ga rak	toe
	top	tower	dang geun	carrot	eo rin ae	child
	ddae	dirt	jun too	battle	un jun ja	driver
	jeok	enemy	um ryo	beverage	sa moo sil	office
	pyo	table	gyo whai	church	joo meo ni	pocket
	noon	snow	do ro	road	baet sa ram	seaman
	tul	frame	nal jja	date	dae gyoo mo	large scale
20-Word Lists	ssi	seed	jong ee	paper	nong san mool	farm product
	wang	king	ma dang	garden	do seo gwan	library

1-Syllable Words		2-Syllable Words		3-Syllable Words	
Korean	Translation	Korean	Translation	Korean	Translation
byung	bottle	mu roop	knee	son ba dak	palm
yak	medicine	ji do	map	ho rang ee	tiger
bbeo	bone	ga soo	singer	gyung chal gwan	policeman
kong	bean	seol tang	sugar	ssu rae gi	waste
sal	flesh	do gu	instrument	cham gi rum	sesame oil
noe	brain	wheu ga	vacation	baek wha jeom	department store
pool	grass	poong gyung	landscape	joo in gong	hero
dal	moon	tae yang	sun	um sik jum	restaurant
tum	opening	soo young	swimming	mool go gi	fish
soop	forest	wha ga	painter	geun ro ja	worker
won	circle	bok do	corridor	soai go gi	beef
cha	tea	yoo ri	glass	whu bo ja	candidate
ggun	string	nong jang	farm	a beo nim	father
jui	mouse	ba kwui	wheel	pee hae ja	victim
teok	jaw	dae moon	gate	ba goo ni	basket
gan	liver	chi ma	skirt	jeol moo ni	youth
mot	nail	u san	umbrella	yae sool ga	artist
al	egg	gol mok	alley	naeng jang go	refrigerator

Figure 1.

U-shaped serial-position curves of free-recall performance in bilinguals' L1 and L2. Error bars represent Standard Deviations. Asterisks* are used to mark a significant difference between L1 and L2 at $p < 0.05$.

Figure 2. Free-recall performance in bilinguals' L1 and L2 in the pre-recency and recency regions. Error bars represent Standard Deviations. Asterisks* are used to mark a significant difference between L1 and L2 at $p < 0.05$.

Figure 3.

Free-recall performance in bilinguals' L1 and L2 on 10-word lists, 15-word lists, and 20-word lists. Error bars represent Standard Deviations. Asterisks* are used to mark a significant difference between L1 and L2 at $p < 0.05$.

Table 1

Demographic Characteristics of Bilinguals

	<i>L1</i> <i>Mean and SD</i>	<i>L2</i> <i>Mean and SD</i>	<i>t</i> -test
Age of Acquisition	1 (1.2)	11.3 (2.8)	$t(19) = -15.25^*$
Years in L1/L2-Speaking Country	25.2 (4.8)	5.1 (3.06)	$t(19) = 14.26^*$
Percent of Daily Exposure to L1/L2	41.2 % (14.6)	57 % (17.7)	$t(19) = -2.21^*$
Contribution of Friends to L1/L2 Learning (zero-to-ten scale)	8.7 (1.6)	6.6 (2.9)	$t(18) = 2.63^*$
Contribution of Family to L1/L2 Learning (zero-to-ten scale)	9.3 (1.3)	0.9 (2.0)	$t(19) = 17.47^*$
Contribution of Watching TV to L1/L2 Learning (zero-to-ten scale)	6 (2.5)	6.5 (2.3)	$t(19) = -0.82$
Contribution of Reading to L1/L2 Learning	7.9 (2.0)	8.1 (1.8)	$t(19) = -0.43$
Exposure to Interacting with Friends in L1/L2 (zero-to-ten scale)	6.6 (2.8)	5.5 (1.7)	$t(19) = 1.38$
Exposure to Interacting with Family in L1/L2 (zero-to-ten scale)	6.6 (3.4)	0.3 (0.8)	$t(19) = 8.03^*$
Exposure to Watching TV in L1/L2 (zero-to-ten scale)	4.6 (2.7)	5.6 (2.3)	$t(19) = -.30$
Exposure to Reading in L1/L2 (zero-to-ten scale)	5.0 (2.8)	8.2 (1.9)	$t(19) = -4.83^*$
Self-Rated L1/L2 Speaking Proficiency (zero-to-ten scale)	9.4 (1.0)	6.1 (1.7)	$t(19) = 9.08^*$
Self-Rated L1/L2 Understanding Proficiency (zero-to-ten scale)	9.4 (1.1)	6.5 (1.7)	$t(19) = 7.71^*$
Self-Rated L1/L2 Reading Proficiency (zero-to-ten scale)	9.3 (1.4)	7.6 (1.5)	$t(19) = 4.99^*$

Note:

* Significant differences between L1 and L2 are asterisked at the $p < 0.05$.