Running Head: L1-ORTHOGRAPHIC TRANSFER IN BILINGUALS

The Acquisition of an Artificial Logographic Script and Bilingual Working Memory:

Evidence for L1-specific Orthographic Processing Skills Transfer in Chinese-English

Bilinguals

Renata F. I. Meuter

and

John F. Ehrich*

Queensland University of Technology

Corresponding author:
Renata Meuter
School of Psychology and Counselling
Kelvin Grove campus
Queensland University of Technology
Brisbane QLD 4059
r.meuter@qut.edu.au

* Now at the School of Education, Edith Cowan University, Perth 6050, Australia
j.ehrich@ecu.edu.au

KEY WORDS: BILINGUALISM, WORKING MEMORY, LOGOGRAPHIC PROCESSING, LANGUAGE LEARNING, LANGUAGE TRANSFER

Abstract

Studies of orthographic skills transfer between languages focus mostly on working memory (WM) ability in alphabetic first language (L1) speakers when learning another, often alphabetically congruent, language. We report two studies that, instead, explored the transferability of L1 orthographic processing skills in WM in logographic-L1 and alphabetic-L1 speakers. English-French bilingual and English monolingual (alphabetic-L1) speakers, and Chinese-English (logographic-L1) speakers, learned a set of artificial logographs and associated meanings (Study 1). The logographs were used in WM tasks with and without concurrent articulatory or visuo-spatial suppression. The logographic-L1 bilinguals were markedly less affected by articulatory suppression than alphabetic-L1 monolinguals (who did not differ from their bilingual peers). Bilinguals overall were less affected by spatial interference, reflecting superior phonological processing skills or, conceivably, greater executive control. A comparison of span sizes for meaningful and meaningless logographs (Study 2) replicated these findings. However, the logographic-L1 bilinguals' spans in L1 were measurably greater than those of their alphabetic-L1 (bilingual and monolingual) peers; a finding unaccounted for by faster articulation rates or differences in general intelligence. The overall pattern of results suggests an advantage (possibly perceptual) for logographic-L1 speakers, over and above the bilingual advantage also seen elsewhere in third language (L3) acquisition.

The Acquisition of an Artificial Logographic Script and Bilingual Working Memory:
Evidence for L1-specific Orthographic Processing Skills Transfer in Chinese-English
Bilinguals

The possible transfer of first language (L1) logographic processing skills to
the reading of a second language (L2) has received scant attention. One exception is a
study that investigated the acquisition and processing of an artificial logographic
script in language learners with different L1-orthographic backgrounds: Chinese-
English bilinguals (logographic-L1 users), English-French bilinguals and English
monolinguals (both alphabetic-L1 users) (Ehrich & Meuter, 2009). The study was
unique because it explored the transfer of L1-specific logographic processing skills,
shifting the focus from alphabetic to logographic L2 reading. The logographic-L1
users (Chinese-English bilinguals) outperformed the alphabetic-L1 users (English-
French bilinguals and English monolinguals) on a lexical decision task involving the
recognition of pre-learnt artificial logographs from a set of structurally similar and
dissimilar items. Their superior performance, combined with the virtually identical
performance of the English-French bilinguals and English monolinguals, suggests that
a bilingual language learning history per se was not providing any cognitive
processing benefit effects. Indeed, we argued that the Chinese-English performance
advantage was likely the result of superior visual processing skills. That is, the
Chinese-English bilinguals were able to transfer specific L1-logographic (visual)
processing skills to an orthographically congruent logographic L2, thus facilitating
logographic-L2 processing (Ehrich & Meuter, 2009). Several studies provide evidence
for such processing differences in performance (e.g., Chen & Tsoi, 1990; Koda, 1999,
Tavassolli, 2002; see also Chen, Fu, Iversen, Smith, & Matthews, 2002; Tan, Liu,
Perfetti, Spinks, Fox, & Gao, 2001; Yamaguchi, Toyoda, Xu, Kobayashi, & Henik,
2002). However, while our data supported the notion that language learners transfer
L1-specific logographic processing skills to facilitate processing a logographic-L2
script, the precise nature of such transferable L1-specific skills has yet to be
determined.

To investigate whether or not the L1-specific skills that were transferred to L2
logographic processing were indeed visual or other (e.g., phonological), we focused
on working memory (WM) paradigms as a means to investigate visual and verbal
processing systems in isolation. Jonides (2000) described WM as a set of subsystems
that subserve different sorts of information processing. These subsystems handle

verbal and visual information (through the phonological loop and the visuo-spatial sketchpad respectively) (Baddeley, 1986, 1990). Access to these verbal and visual subsystems can be restricted by verbal and visual interference during various concurrent tasks (Baddeley, 2002). For example, verbal interference tasks (such as articulatory suppression) disrupt phonological rehearsal in WM and, consequently, result in a greater reliance on processing in the visual subsystem. Alternatively, tasks that disrupt visuo-spatial processing result in a greater reliance on processing in the verbal subsystem. Therefore a WM task using artificial logographic stimuli, with and without concurrent interference, allows the examination of variant L1-orthographic users' reliance on visual and phonological processing. Specifically, if L1-logographic users are more affected by spatial interference, it may be that they rely comparatively more on visual processing than their L1-alphabetic counterparts.

Accordingly, to determine whether the characteristics of the first acquired and dominant L1 provide processing advantages, if congruent with those of the new language, we focused on WM ability when processing another, newly acquired language. This idea has not received much attention, yet there are some compelling reasons to predict that language learners may transfer L1-specific orthographic processing skills to facilitate the ease of processing an orthographically congruent L2 (or third language (L3)) in WM. First, there are significant differences between orthographic systems (see Mattingly, 1992). Second, there is evidence that different orthographic types require different types of processing and that L1-specific orthographic processing skills can be transferred to orthographically congruent L2 (or L3) processing contexts (e.g., Akamatsu, 2003; Chikamatsu, 1996; Ehrich & Meuter, 2009; Koda, 1999, 2000; Muljani, Koda, & Moates, 1998). Third, WM performance correlates with reading ability (alphabetic L2) (see Harrington & Sawyer, 1992; Williams, 1999). Therefore it is reasonable to assume that L1-specific orthographic processing skills may similarly impact on L2 (or L3) WM ability, and could have a beneficial effect if orthographic congruency is a determining factor of any L2 (or L3) WM processing benefit.

Orthographic Differences and Working Memory

The three main types of scripts (alphabets (e.g., English), syllabaries (e.g., Japanese Kana) and logographies (e.g., Chinese characters) differ in a number of ways, most obviously in their structural characteristics. Logographic scripts such as Chinese characters (including Japanese Kanji), are structurally (visually) complex,

with some characters containing up to 24 individual strokes (Shu, Chen, Anderson, Wu, & Xuan, 2003). In contrast, letters of the alphabet (and syllabaries) are structurally relatively simple. Furthermore, the English alphabet (for example) only has 26 letters in contrast to the thousands of Chinese characters that need to be learned. In mainland China, primary school children internalize approximately 2,570 distinct Chinese characters as part of their general literacy (Shu et al., 2003).

There are also significant processing differentials between logographic and alphabetic script. Logographic script consists of words which are morphemes, while alphabetic and syllabic scripts consist of words made up of phonemes and syllables, respectively. Critically, while morphemes consist of individual orthographic structures with a phonological and a semantic association, phonemes and syllables have only a sound and no meaning association. Only when phonemes (or syllables) are assembled are words formed, complete with a pronunciation code and a semantic association. By contrast, there is no assemblage of Chinese morphemes, and meanings and pronunciations are accessed directly from memory.[1]

Such structural and processing differentials suggest that the processing of logographic script may rely more on visual processing than alphabetic or syllabic script. Indeed, there is evidence that logographic Chinese and alphabetic English require different cognitive processing orientations. It is possible that logographic Chinese requires more visually-orientated cognitive processing than alphabetic English, which may require more phonologically-orientated processing (see Ehrich, Zhang, Mu, & Ehrich, 2012). For example, visual skills have been found to be a reliable predictor of Chinese (logographic) children's reading skill, whereas phonological skills reliably predict British (alphabetic) children's reading skill (e.g., Hanley & Huang, 1997). Furthermore, logographic and alphabetic/syllabic scripts may require different types of processing in WM.

Such differentials in WM processing have been reported in L1 logographic and alphabetic (or syllabic) background language users who processed their respective L1 scripts. For example, the visuo-spatial sketchpad (VSSP; see Baddeley, 1986, 1990) has been found to play a role in the retention and recall of logographic Chinese characters (e.g., Hue & Erickson, 1988; Kimura, 1984; Mou & Anderson, 1981; Zhang & Simon, 1985) but not in the storage of alphabetic English language items (e.g., Baddeley, 1966; Cheung & Kemper, 1994; Cimbalo & Laughery, 1967). When Japanese native speakers judged whether pairs of words displayed in Kana or Kanji

scripts were semantically related (e.g*., tax/import*) or unrelated (e.g., *safe/teapot*), articulatory suppression interfered with the processing of Kana (syllabic) script but not Kanji (logographic) script, suggesting that the processing of phonographic script relies on rehearsal in the phonological loop (Kimura, 1984). In contrast, the processing of logographic script can bypass the phonological loop through substitution with the visuo-spatial sketchpad (or some other capability).

Neuroanatomical evidence also supports differential processing of logographic and alphabetic scripts. For example, when Chinese speakers judged a pair of Chinese characters on their semantic and homophonic relatedness, functional magnetic resonance imaging (fMRI) showed that, although there was considerable topographic overlap with areas strongly associated with alphabetic reading, logographic reading peak activations were found in the mid-dorsal prefrontal region, an area associated with the mediation of spatial and verbal WM but one that few alphabetic reading fMRI studies highlight (Tan et al., 2001). This distinct topography may result from the greater visual-spatial complexity of logographic script. Consistent with this interpretation there is further evidence that a logographic-L1 background might enhance visual processing. For example, logographic-L1 users outperformed their alphabetic counterparts in visual recognition and recall (e.g., Flaherty, 2000; Mann, 1985), and tests involving spatial ability (e.g., Salkind, Kojima, & Zelniker, 1978; Stevenson & Lee, 1990; Tavassolli, 2002). However, few studies have investigated the WM performance of logographic versus alphabetic-L1 speakers in their respective L1. Fewer still have investigated L2 working memory (Service, Simola, Metsanheimo, & Maury, 2002).

Most L1 WM studies found no superiority in performance by logographic-L1 participants over their alphabetic-L1 counterparts, (e.g., Leung, 2006; Luer, Becker, Lass, Yunqiu, Guopeng, & Zhongming, 1998; Stigler, Lee, & Stevenson, 1986). However, these studies focused more on the role of the phonological loop. For example, Luer et al. (1998) reported a superior L1 WM span in Chinese speakers compared to German speakers, a finding ascribed to the shorter articulation times of the Chinese words. When random shapes were used which could not be verbalized, the WM span superiority of the Chinese speakers dissipated. Luer et al. (1998) argued that processing items in the visuo-spatial sketchpad may not advantage logographic-L1 background speakers. However, they did not include concurrent articulatory suppression on any tasks. Articulatory suppression would have prevented

phonological rehearsal and allowed for the observation of processing solely in the visuo-spatial sketchpad. Also, temporal word length (i.e., articulation time) was not controlled for, a critical aspect accounted for in our studies.

Bilinguality and Working Memory

In addition to processing differentials in WM for logographic and alphabetic scripts, bilinguality per se might confer differences in processing. For example, bilinguals have an advantage over monolinguals when acquiring another (third) language (e.g., Cenoz, 2000; Cenoz & Valencia, 1994; Jessner, 1999; Klein, 1995; Thomas, 1988), have enhanced metalinguistic awareness (e.g., Bain & Yu, 1978; Bialystok, 1987; Cummins, 1978; Ehrich & Meuter, 2009), develop skills related to controlling attention at an earlier age than monolinguals (e.g., Bialystok, 1997, 1999, see Bialystok, 2007 for review), and, importantly, have superior WM performance (e.g., Ardila, Rosselli, Ostrosky-Solis, Marcos, Granda, & Soto, 2000; Bialystok, Craik, Klein, & Viswanathan, 2004; Ransdell, Arecco, & Levy, 2001). However, most studies of bilingual WM have used within-subjects designs that examine bilingual processing of their two languages (Bialystok et al., 2004). Few studies compare adult bilingual and monolingual performance on WM processing (Bialystok et al., 2004; Cook, 1997), yet a bilingual background may benefit WM performance (e.g., Ardila et al., 2000; Bialystok et al., 2004). For example, on a digit span (forward) task Spanish-English bilinguals attained higher than average spans in L1 compared with Spanish monolinguals (Ardila et al., 2000). A similar bilingual advantage emerged for Tamil-English bilinguals whose WM performance was less affected by age-related decline than that of their English-speaking monolingual peers (Bialystok et al., 2004).

Enhanced central executive function ability in bilinguals might account for these performance advantages. The frequent requirements to switch between two competing language systems, a task requiring considerable control of attentional resources, may explain superior attentional control in bilingual children on problem-solving tasks compared to monolingual children (Bialystok, 2007). Adult bilinguals may similarly have superior ability at suppressing irrelevant information in L1 WM tasks (e.g., Ransdell et al., 2001).

WM has been investigated largely in relation to bilingual or monolingual language users processing their respective L1 orthographies. To date few studies have investigated WM in the context of an L2 or L3, and then the focus has been the degree to which L2 proficiency in an alphabetic language can affect WM processing of

alphabetic script (e.g., Service et al., 2002; Van den Noort, Bosch, & Hugdahl, 2006). Few studies consider logographic-L1 background Chinese and Japanese users' performance on alphabetic-L2 WM tasks (Harrington & Sawyer, 1992; Juffs, 2004; Leung, 2006). For example, Leung (2006) used serial recall when comparing Chinese-English and Spanish-English bilinguals, and English monolinguals, on an L2 (English) word span task. A monolingual advantage emerged ($M = 4.4$), with no word span differences between the Chinese-English and Spanish-English bilinguals ($M = 3.5$ vs. $M = 3.3$). However, as in Luer et al. (1998), temporal word lengths were not controlled for and faster rehearsal rates in the proficient native English speakers are a likely explanation for their finding.

Importantly, findings indicating the importance of phonological processing in the recall of Chinese characters (e.g., Hue & Erickson, 1988; Mou & Anderson, 1981; Zhang & Simon, 1985) do not conflict with the main argument posited here. Phonological processing is critical to the recall of words in short-term memory (STM) and WM, regardless of orthographic type. Our main argument is that the inculcation of a logographic-L1 may enhance visual processing skills which then can be transferred to L2 orthographic processing. Phonological processing is important in Chinese WM and in reading (particularly after words have been identified). When it is argued that the inculcation of a logographic orthography orients language learners toward visual processing, it is meant relative to the degree to which the inculcation of a phonographic language may do so. Thus, the important role that phonology plays in processing Chinese characters in WM does not detract from the argument that visual processing may be more important to Chinese character processing than English word processing.

At least one reliable study showed a WM visuo-spatial superiority of logographic-L1 Chinese over alphabetic-L1 (Greek) language users (Demetriou, Kui, Spandoudis, Christou, Kyriakides, & Platsidou, 2005). This finding suggests that, within the WM research paradigm, language background effects can influence processing styles and, importantly, can be detected. Moreover, Cheung and colleagues (e.g., Cheung & Kemper, 1993, 1994; Cheung, Kemper, & Leung, 2000) found that, during the recall of Chinese characters in a WM serial recall task, either a visual-spatial processing or a non-articulatory phonological store played an important role. Furthermore, Chinese-English participants were not completely dependent on verbal rehearsal. This observation contrasts with their findings on the recall of English

words, which was completely dependent on verbal rehearsal via the phonological loop. Taken together, these findings suggest an orientation toward visual processing by logographic-L1 speakers.

As yet, no studies have investigated L2 WM, from the perspective of the impact of a logographic-L1 background on the acquisition and use of a similar (i.e., logographic) language. Therefore, in addition to the possible transfer of L1 orthographic processing skills to L2 WM, we wanted to determine whether a bilingual performance advantage obtains when processing a novel, artificial logographic script (an L3 for the bilinguals) in WM and, if so, whether orthographic congruency increases the advantage. Furthermore, given the reported processing differentials for logographic and alphabetic scripts, we explored whether subcomponents of WM would be variably recruited depending on L1-specific experience.

Experiment 1

To explore logographic transfer and the purported bilingual advantage when acquiring another language, we devised a unique language learning and WM paradigm involving the creation of an artificial logographic script (see Ehrich and Meuter (2009) for full details of the script). The artificial logographs consisted of 10 visually complex structures that were each paired with a specific meaning. The artificial logographs contained no phonetic clues that could be accessed from their orthographic form. In this way, the artificial script mirrors authentic Chinese script, which consists of many characters devoid of phonetic clues (cf. Gao, 1983; Shu et al., 2003). Importantly, for each artificial logograph a high frequency L1 meaning was chosen in English and Chinese (cross-language equivalents).

All participants acquired the new script and were subsequently tested on their performance when processing this script in WM under several conditions (with and without concurrent interference). If logographic-L1 participants have an enhanced visual processing capability compared to alphabetic-L1 participants, then they should outperform the alphabetic-L1 participants on the WM task involving concurrent articulatory suppression, which impedes the use of phonological rehearsal strategies. By contrast, the L1 logographic users should demonstrate inferior performance to the alphabetic-L1 users when undertaking the concurrent spatial interference task. This latter prediction was based on the strong connection of Chinese orthographic processing to visual/motoric skills (Endo, 1988; Sasaki, 1987). The task without any interference is (arguably) a central executive task, in that it is likely that both visual

and verbal subsystems would be activated in the retrieval of the artificial logographs. Both bilingual groups were expected to perform equally well (or poorly) on this task, in line with Demetriou et al.'s (2005) observations of similar performance in logographic-L1 Chinese and alphabetic-L1 Greek users during central executive tasks.

Method

Participants

Seventeen Mandarin (L1)-English (L2) bilinguals (8 males, 9 females) from mainland China (mean age = 25, SD = 4), 13 English (L1)-French (L2) bilinguals (4 males, 9 females) (mean age = 27, SD = 6), and 22 English monolinguals (4 males, 18 females) (mean age = 22, SD = 6) participated. All were current university students in Australia and received either a fee or course credit for their participation; all had normal or corrected vision. A language background questionnaire established that the English-French bilinguals (M = 5.1, SD = 1) and the Chinese-English bilinguals (M = 5.6, SD = 0.7) were equally proficient in their L2, $t(28)$ = -1.57, ns (averaged across speaking, reading, comprehension and writing on a 7 point self-rating scale) (see Appendix 1 Table 1 for details on age of L2 acquisition). To control for performance differences related to IQ, the Raven's Advanced Progressive Matrices Test (1962) was administered. No group differences were found, $F(2, 51)$ = 1.99, MSE = 24.67, ns.

Materials

Artificial Logography. One basic structural element from Akkadian cuneiform (a triangle with a straight line emanating from its peak; Marcus, 1978) was manipulated to form 10 artificial logographs (Targets). Five of these consisted of 3 elements (Simple); the other 5 Targets contained 6 elements (Complex; see Figure 1).

Insert Figure 1 here

Each Target was matched with a meaning association (all concrete nouns) in Mandarin and English to create a meaningful artificial logographic script. The Chinese and English meanings were virtually identical, also in grammatical function. In Chinese, each item had one general meaning as well as a unique pronunciation at the level of tone (Concise English-Chinese Chinese-English Dictionary, 1999).

Temporal word lengths for associated meanings were equal across English (M = 574, SD = 81) and Chinese (M = 578, SD = 46), $t(18)$ = -.162, ns (see Appendix 2, Table 1 for more details). All Chinese and English words were high frequency (> 30

per million; taken from the Modern Chinese Frequency Dictionary (1986) and Francis and Kučera (1982), respectively).

Working Memory Tasks. Three WM tasks were devised: the WM-Normal (without concurrent interference), WM-Articulatory Suppression (with concurrent vocal articulation) and WM-Visuo-Spatial Suppression tasks (with concurrent finger tapping), all using the same stimulus presentation process. Artificial logographs were presented singly and randomly, for 1s each, in the centre of a computer screen in sequences consisting entirely of Simple or Complex logographs. Sequences started with a 2-item length progressing to a maximum of 9 items, and were presented in blocked fashion as follows. At each sequence length a block of 4 sequences of Simple logographs was always followed by a block of 4 sequences of Complex logographs. Sequence length increased by one on completion of two such consecutive blocks. For sequences of 5 or less, each logograph occurred only once per sequence. For longer sequences individual logographs could recur but never consecutively or more than twice per sequence. Stimulus presentation and data collection in this and the subsequent experiment was controlled using E-Prime (Schneider, Eschman, & Zucchoiotto, 2001). Responses were recorded using the number keys at the top of a keyboard. Each key had a picture of an artificial logograph pasted onto it (Simple condition = keys 1–5; Complex condition = keys 6–0). The remaining keys were blacked out. A wooden touch pad was created for the spatial interference task by attaching 4 wooden plates (70 mm x 70 mm) in a square formation (equidistant) to a square wooden block (25 cm x 25 cm) (cf. Rumiati & Tessari, 2001).

Procedure

Learning phase. The Targets and their associated meanings in the participants' L1 were acquired using flash cards. The Simple Targets were mastered first to the criteria of (1) three consecutive, errorless runs of full recall and (2) each structure drawn correctly once from memory. Each unsuccessful recall attempt was followed by a revision. The same procedure was used for the Complex Targets. On successful acquisition of both sets, a final overall meaning recall test was administered to the criterion of one errorless run. Time taken to fulfil the learning criteria was measured using a stopwatch.[2] Participants were tested individually, also in the testing phase.

Testing phase. The WM-Normal task was presented first, followed by the WM-Articulatory Suppression and WM-Visuo-Spatial tasks in counterbalanced order.

The Raven's Progressive Matrices Test (1962) was administered last. For each task instructions appeared on the screen in the participants' L1. A practice session was presented first, consisting of one 4-sequence block of Simple Targets and another of Complex Targets at 2-item sequence length. The practice session was repeated if accuracy fell below 75%. The experimental blocks were initiated by pressing the spacebar. A 500 ms central fixation point appeared 4s later, immediately followed by the first target. A question mark 4s after the display of the final target prompted serial recall of targets. Responses were typed as quickly and accurately as possible using the dominant index finger. With each set of Simple and Complex blocks, sequence length increased by one. The task terminated when response accuracy across two consecutive blocks of Simple and Complex Targets of identical sequence length fell below 75%. Response accuracy for a given sequence length was calculated by averaging response accuracy per block across the two blocks.

In the WM-Normal task, no concurrent suppression was carried out while viewing the items. In the WM-Articulatory Suppression task, participants audibly repeated "Coca-Cola"[3] at a rate of 2 phrases per second. Participants began repeating the phrase 4s prior to the presentation of the first target and continued for 4s after the presentation of the last target. A computer-generated tone signaled the beginning and end of the suppression utterances. A practice session was administered first, using articulatory suppression. In the WM-Visuo-Spatial Suppression task, participants tapped a zigzag pattern on the wooden touch pad plates with the dominant index finger at an approximate rate of three taps per second. Tapping began 4s prior to the display of the first stimulus item and concluded 4s after the display of the last stimulus item. A practice session was administered first, with spatial suppression. Task difficulty was rated on a 5-point Likert scale at the conclusion of each task, as part of a larger questionnaire discussed elsewhere (see Ehrich & Meuter, 2012).

Design and Analysis

For this and all subsequent analyses, memory span was determined by the longest item sequence attained with a minimum accuracy of 75%. When assumptions were met, analyses of covariance (ANCOVAs) were carried out with Group (Chinese-English bilinguals vs. English-French bilinguals vs. English monolinguals) as the between-subjects factor, Task (WM-Normal vs. WM-Articulatory Suppression vs. WM-Visuo-Spatial Suppression) and Target Complexity (Simple vs. Complex) as the within-subjects variables, with the Raven scores as the covariate. Greenhouse-Geisser

corrections were applied as needed. A Kruskal-Wallis test was used to analyse task difficulty ratings. Calculations for all non-parametric planned comparisons followed Siegel and Castellan (1988).

Results

Working Memory Performance

Mean memory spans (adjusted) with and without concurrent articulatory or visuo-spatial suppression for the three groups are shown in Table 1. Importantly, under conditions of concurrent interference, spans were consistently larger for the Chinese-English bilinguals. A Group x Task x Target Complexity mixed ANCOVA, after accounting for IQ differences, revealed no significant three-way interaction, $F < 1$. However, there was a significant Group x Task interaction, $F(3.6, 85.3) = 3.14$, $MSE = 6.8$, $p < .025$. Planned comparisons ($\alpha = .05$) for each task revealed no group differences in the WM-Normal span. However, on the WM-Articulatory Suppression task the Chinese-English bilinguals experienced significantly less interference than the English monolinguals, $p = .001$. No significant differences were found between the English-French bilinguals and English monolinguals or between the two bilingual groups. On the WM-Visual-Spatial suppression task, both the Chinese-English bilinguals and the English-French bilinguals experienced significantly less interference than the English monolinguals, $p < .001$ and $p = .01$, respectively. The spans for the bilingual groups did not differ measurably. Planned comparisons for each group support the observation that the monolinguals were much affected, and equally so, by concurrent interference in both modalities, $ps < .001$. For both bilingual groups, irrespective of L1 background, performance was significantly worse with articulatory suppression, $ps < .015$, but the spans obtained without inference and with visuo-spatial interference were virtually identical. There was a significant Group main effect, $F(2, 48) = 9.83$, $MSE = 39.30$, $p < .001$. No Target Complexity main effect emerged, $F < 1$, nor any interactions with this factor, indicating that visual complexity did not affect serial recall.

Insert Table 1 here

Task Difficulty Ratings

WM-Normal task. Thirty-eight percent of the English-French bilinguals and 27% of the English monolinguals found recalling the artificial logographs on the WM-Normal task "difficult", compared with only 18% of the Chinese-English bilinguals, $\chi^2 (2) = 6.4$, $p < .05$. A further analysis comparing Chinese-English

bilinguals (logographic background) with English-French bilinguals and English monolinguals combined (alphabetic background) revealed that the Chinese-English bilinguals found the task significantly easier than their L1-alphabetic counterparts, χ^2 (1) = 6.4, $p < .02$.

WM-Articulatory Suppression task. The difficulty ratings were similar across groups, with most participants describing their recall of artificial logographs viewed while concurrently articulating a phrase as "very difficult" or "difficult", χ^2 (2) = 3.1, *ns.*

WM-Visuo-Spatial Suppression task. Most monolinguals (55%) found recalling artificial logographs viewed with concurrent visuo-spatial suppression "very difficult" compared to the Chinese-English (12%) and English-French bilinguals (15%), χ^2 (2) = 13.1, $p < .003$. Planned comparisons revealed that both bilingual groups (whose ratings did not differ) rated the task as significantly easier than did the English monolinguals, ps $< .05$.

Discussion Experiment 1

As predicted all groups performed similarly on the WM-Normal task (without any concurrent interference), a finding consistent with prior research reporting similar performance in logographic and alphabetic language users on central executive tasks (e.g., Demetriou et al., 2005). The WM-Normal task was categorized as a central executive task, because it was likely that both visual and verbal processing subsystems were activated in the recall of the artificial logographic items. We predicted that language learners with a logographic-L1 background would transfer their L1 orthographic processing skills to a logographic-L2 script and hence outperform alphabetic-L1 learners. Based on earlier findings (Ehrich & Meuter, 2009) we predicted that the requirement to recall recently acquired artificial logographs would preferentially recruit the visuo-spatial sketchpad. Given the similarity between this new script and Mandarin Chinese (both logographic scripts), we predicted that Chinese-English bilinguals might have better developed skills at processing and retaining visual information, and would therefore show superior performance under articulatory suppression.

The results support our contention to a degree. When access to the phonological loop was restricted and, arguably, reliance on the visuo-spatial sketchpad increased through articulatory suppression, the Chinese-English bilinguals showed slightly increased spans compared to the English-French bilinguals (adjusted

mean spans 2.8 vs. 2.2) but not significantly so. However, they did outperform the English monolinguals (mean span = 1.6). The English-French bilinguals showed slightly higher spans than the English monolinguals (adjusted mean spans 2.2 vs. 1.6) but the difference was not significant. This pattern of results suggests that a logographic-L1 background provides some superior visuo-spatial sketchpad processing capability and enables transfer of specific L1 orthographic processing skills to an orthographically congruent L2 but bilinguality per se may also confer some advantage on WM tasks. The psychometric data supports this interpretation. For example, the Chinese-English bilinguals rated the processing of the artificial logographs during the WM-Normal task as significantly easier than the English-French bilinguals and English monolinguals. These ratings suggest that their logographic-L1 background facilitated learning in some way and are consistent with their comparatively larger spans on the WM-Visuo-Spatial Suppression task.

The bilinguals' performance, irrespective of L1-logographic background, was relatively unaffected by concurrent spatial tapping. Thus bilinguals appear to be able to compensate for the lack of a visuo-spatial capability through the substitution of an alternative processing subsystem, such as the phonological loop (see Cheung & Kemper, 1994; Luer et al., 1998). Bilinguality appears to facilitate the ease of recall of the artificial logographic script (an L3), suggesting that bilinguals may have greater executive control (see also Ardila et al., 2000; Bialystok et al., 2004). That is, at least on WM tasks, bilinguals can switch readily between processing in one subsystem with processing in an alternate system irrespective of which languages they speak. By contrast, visuo-spatial suppression halved the span for the monolinguals (see Table 1), who found this task very difficult. These findings further supports our and previous observations that a bilingual background may provide L2 WM performance benefits, in this case enabling the effective use of the phonological loop for rehearsal.

The importance of the phonological loop in rehearsing meaningful L2 artificial logographs underscores the importance of phonology in WM of logographic-L2 items and is consistent with several L1 Chinese language studies indicating that phonology is critical to the recall of logographic items (e.g., Hue & Erickson, 1988; Mou & Anderson, 1981; Zhang & Simon, 1985). We further observed that the phonological loop played a far superior role in the recall of logographic items than did the visuo-spatial sketchpad. Increased reliance on the visuo-spatial sketchpad might have been expected for the structurally more complex items, however target complexity did not

play a role. However, our stimuli were perhaps not complex enough to reveal any possible reliance on visual processing.

The present findings could also be explained by superior phonological processing skills in bilinguals. For our English-French bilinguals, superior phonological skills might explain why they outperformed monolinguals on the WM-Visuo-Spatial Suppression task. There is some empirical support for this position. For example, Campbell and Sais (1995) found that preliterate English-Italian bilingual children were superior to English monolingual children on phonological processing tasks. Additionally, the phonological loop plays a crucial role in L2 acquisition (e.g., Baddeley, Gathercole, & Papagno, 1998; Cheung, 1996; Ellis & Sinclair, 1996; Papagno, Valentine, & Baddeley, 1991). It is conceivable that, by virtue of acquiring an L2, phonological processing skills become more finely honed. However, this explanation is highly speculative. One way of testing this possibility directly is by comparing L1 spans across our logographic- and alphabetic-L1 groups.

In addition, it is possible that learners may have relied on the logographs' associated L1 meanings to assist their retention (and thus also increasing reliance on phonological processing). Indeed, using a lexical decision task on the same, well-learned set of artificial logographs, we found that meaningful (and legal) items were rejected more slowly (Ehrich & Meuter, 2009). It is important therefore to establish directly the L1 word span for these Chinese and English meaning associations. Doing so also allows further exploration of the effect of bilinguality on L1 WM processing. Furthermore, if the bilinguals' superior performance is due to their enhanced phonological ability, then it should also appear when processing L1 words. It may be that the learned meaning associations biased learners towards phonologically-driven processing. Accordingly, we also tested WM ability for a set of novel, not previously seen, artificial logographs devoid of meaning. This novel set should be difficult to verbalize and may force greater reliance on visual processing, potentially benefitting L1-logographic Chinese users.

Experiment 2

Here we test performance on new, not previously studied artificial logographs, free from meaning and phonological associations. Rehearsing items from this novel set may preferentially recruit the visuo-spatial sketchpad and reveal the logographic-L1 advantage described by Ehrich and Meuter (2009). We also used an L1 word span task using the semantic associations of the artificial logographs (from Experiment 1)

in the participants' respective L1s (Chinese and English). For the recall of English words, the phonological loop is completely autonomous (e.g., Cheung & Kemper, 1994). Therefore, if the English-French bilinguals outperform the English monolinguals on an English (L1) WM task, their WM superiority can be ascribed to their enhanced phonological rehearsal capability. However, if the English-French bilinguals perform similarly to the monolinguals, then the bilingual performance advantage attained in Experiment 1 (WM-Visuo-Spatial Suppression task) cannot be attributed to enhanced phonological rehearsal capability and, instead, may reflect superior ability to control executive functions.

WM research has tended to focus on digit span (Ardila, 2003). However, Chinese language items (particularly digits) often have shorter temporal durations than English words (e.g., Stigler et al., 1986) and, when not controlled for, result in larger WM spans for Chinese speakers (e.g., Luer et al., 1998)). Therefore, as in Experiment 1, temporal word length of meaning associations was controlled (see Ehrich & Meuter, 2009). If a bilingual advantage operates in WM (as the findings for Experiment 1 suggest), it is conceivable that both bilingual groups will outperform the monolinguals on this task

Experiment 2 Method

Participants

As in Experiment 1.

Materials

Meaningless Artificial Logographs. A new set of 10 artificial logographs was created (cf. Experiment 1) but no meanings were assigned. The Meaningless set also consisted of 5 Simple and 5 Complex Targets (see Figure 2).

Native Language Items. The Chinese and English meaning associations of the artificial logographs in Experiment 1 served as the stimuli.

Insert Figure 2 here

Procedure

The two tasks were counterbalanced (as were Experiment 1 and Experiment 2). For the Meaningless artificial logographs the procedure was as in the WM-Normal task (Experiment 1), except that the artificial logographs were not pre-learnt. Before the experiment proper began, participants were given time to familiarize themselves with the shape and location of the new targets on the keyboard. The English meanings were pasted onto the top row of a computer keyboard, with the Chinese character

meaning associations pasted directly underneath. Either the English meanings or the characters were concealed, as appropriate. All other keys were blacked out. For the native language items the procedure again followed that of the WM-Normal task, and either Chinese characters (Simsun font, size 28) or English words (Times New Roman, font size 24) were displayed on the screen.

Design and Analysis

WM-Normal spans (Experiment 1) were used (here labelled WM-Meaningful) to explore the effect of meaning on processing the artificial logographs. Where ANCOVA assumptions were met, memory spans were subjected to mixed ANCOVAs with Group (Chinese-English bilinguals vs. English-French bilinguals vs. English monolinguals) as the between-subjects factor, Meaning (WM-Meaningful vs. WM-Meaningless) or Language (L1 vs. Artificial Logography) as the within-subjects variable, and Raven scores as the covariate. Bonferroni adjustments were applied to all planned comparisons throughout.

Results Experiment 2

Mean adjusted memory spans for meaningless and meaningful artificial logographs, and the L1 WM spans for the learned meanings associated with the meaningful logographs are shown in Table 2. First the spans for the meaningful and meaningless logographs are compared, followed by the analysis of differences between L1 span and that for the artificial logography.

Meaning and artificial logographs. After differences in IQ were accounted for, an ANCOVA revealed no Meaning main effect, $F(1, 48)=1.24$, $MSE = 1.67$, *ns*, nor a Meaning X Group interaction, $F(2, 48)=1.84$, $MSE = 2.68$, *ns*. There was a significant Group main effect, $F(2, 48) = 3.35$, $MSE = 10.37$, $p < .05$. Planned comparisons (at $\alpha = 0.05$) revealed that overall, the Chinese-English bilinguals had larger spans for artificial logographs than the English monolinguals. No other comparisons reached significance.

Insert Table 2 here

L1 versus artificial logography. A Group (3) x Language (2) mixed Analysis of Variance (ANOVA) revealed no interaction, $F(2, 48) = 1.61$, $MSE = 1.19$, *ns*. A significant Language main effect, $F(1, 49) = 55.14$, $MSE = 40.65$, $p < .001$, indicated that L1 words were easier to recall than artificial logographs. Planned comparisons to follow up on the Group main effect, $F(2, 49) = 7.81$, $MSE = 14.68$, $p = .001$, confirmed that the Chinese-English bilinguals had greater spans than both the

English-French bilinguals and the English monolinguals, all ps < .01. The alphabetic-L1 speakers did not differ from each other.

Discussion Experiment 2

Meaningless logographs were assumed to be more difficult to label, thus increasing reliance on visuo-spatial processing for memory rehearsal. Given the suggestion that the Chinese-English bilinguals might have superior visuo-spatial processing skills, they were expected to outperform the two L1-alphabetic language learner groups on their recall of the artificial logographs. However, while the Chinese-English bilinguals again did outperform the English monolinguals, their spans for artificial logographs were not measurably larger than those obtained by the English-French bilinguals. While it is possible that bilingual experience might account for the observed advantage, the lack of a similar advantage for the English-French bilinguals suggests another factor might be at play.

When attempting to retain sequences of meaningless artificial logographs, it seems unlikely that participants were relying solely on their visual processing capability. The WM spans for the meaningless logographs were higher than those attained during the recall of meaningful artificial logographs with articulatory suppression (compare Tables 1 and 2). Recall that articulatory suppression disrupted phonological processing and, as a consequence, visual processing only could be relied on for rehearsal. The Chinese-English bilinguals' span for the WM-Articulatory Suppression task was lower than their span for meaningless artificial logographs ($M = 2.8$ vs. $M = 3.9$). Similarly, the spans of the English-speaking groups increased by approximately 0.6. It is conceivable that, in order to aid their recall of the meaningless logographs, participants were also using verbal coding strategies. If participants were spontaneously generating verbal labels for new artificial logographs, the associated rehearsal rates would invariably differ. Given the tendency for Chinese words to have shorter temporal lengths than English words (e.g., Stigler et al., 1986), the performance advantage of the Chinese-English bilinguals over the English monolinguals seen here, suggesting an L1-logographic advantage, should be interpreted with caution.

Interestingly, when performing the task in L1, the Chinese-English bilinguals outperformed both the English-French bilinguals and the English monolinguals. Because the temporal word length of the Chinese and English words was strictly controlled on this task, differences in rehearsal rates for Chinese items cannot be the

explanation. Instead, the Chinese-English bilinguals may have been utilizing more than phonological rehearsal. This interpretation is consistent with Cheung and colleagues' evidence for a quantitatively different short-term store regarding the recall of Chinese words (e.g., Cheung & Kemper, 1993, 1994; Cheung et al., 2000). While the recall of English words revealed a strong linear relationship between the word length and articulation rate, the relationship between Chinese word lengths and their articulation rates was less clearly defined. The word length effect completely disappears for English speakers recalling English language items under concurrent articulatory suppression (Baddeley, Thomson, & Buchanan, 1975; see Baddeley, 1986). However, under the same condition Cheung et al. (2000) found it did not completely disappear during the recall of Chinese language items by Chinese native speakers. They attributed this finding to a short-term phonological store that was independent of articulatory rehearsal, suggesting in effect that a specialized from of processing is associated with the storage of Chinese characters in WM. This specialized storage system may also explain the increased L1 WM capacity of the Chinese-English bilinguals observed in Experiment 2. Importantly, the existence of a short–term store in WM that is dedicated to the processing of Chinese characters indicates that specific L1 orthographies may require specific L1 cognitive processing. The Chinese-English bilinguals' superior performance with the artificial logographs, even if measurably greater only when contrasted with the monolinguals' performance, may similarly reflect such a specialized system.

The lack of a span difference for meaningful and meaningless artificial logographs suggests that semantic processing did not play a critical role, in contrast to our earlier findings of faster rejections of illegal strings of artificial logographs compared to those that were legal and meaningful (Ehrich & Meuter, 2009). Also contrary to predictions, the virtually identical performance by the English-French bilinguals and the English monolinguals when processing the L1 words and the artificial logography indicates that bilinguality per se does not facilitate WM performance. Instead, both these groups appear to have rehearsed L1 items at a similar rate in the phonological loop which, in the recall of English language items, plays a relatively autonomous role (e.g., Baddeley et al., 1975; Cheung & Kemper, 1994; Cimbalo & Laughery, 1967). That is, the temporal length of the word determines its rate of rehearsal in the phonological loop. If bilinguality confers a phonological processing advantage, bilinguals should have attained greater word spans. Recall that

the bilingual advantage in WM processing over monolinguals in Experiment 1 was only attained under the conditions of concurrent visuo-spatial interference indicating (arguably) either superior phonological processing skills or a superior capability to control executive functions (e.g., an enhanced ability to switch the processing focus from the visuo-spatial sketchpad to the phonological loop). The two observations taken together support the notion that the bilingual processing advantage attained in Experiment 1 may have been a result of superior control of attentional resources rather than enhanced phonological rehearsal skills. Prior research indicating that bilinguals tend to have higher levels of control and attention than monolinguals (e.g., Bialystok, 1997, 1999), and that attention and control plays an important role in skilled L2 processing (see Segalowitz & Frenkiel-Fishman, 2005), is consistent with this argument.

In summary, in Experiment 2 some support for L1-orthographic processing skills transfer to the processing of artificial logographs was obtained. The Chinese-English bilinguals outperformed both L1-alphabetic background groups (the English-French bilinguals and the English monolinguals) on the L1 word span task, and also on their overall performance across L1 and the artificial logographs. The cross-linguistic processing differential for the Chinese compared to the English words tentatively supports studies indicating that the phonological loop may not be autonomous in the recall of Chinese words, pointing instead at the possibility of a specialised phonological store independent of articulatory rehearsal used to aid the recall of Chinese characters. Furthermore, bilinguality did not provide any performance benefits, as seen when comparing English word spans in English L1 users. Thus the bilingual advantage of the English-French bilinguals over the English monolinguals in Experiment 1 was probably due to greater attentional control rather than an enhanced phonological rehearsal capability.

General Discussion

At first glance the results from Experiments 1 and 2 appear to suggest that an L1-logographic background does not facilitate the ease of processing artificial logographic items in WM. However, while the Chinese-English performed similarly to the English-French bilinguals, they did outperform the monolinguals on the WM-Articulatory Suppression task (Experiment 1) where the visuo-spatial sketchpad would have been relied on for rehearsal. This observation was replicated in Experiment 2 with meaningful and meaningless artificial logographs. Thus, contrary

to earlier suggestions of a unique role for the visuo-spatial sketchpad in the processing of Chinese characters (e.g., Hue & Erickson, 1988; Zang & Simon, 1985) which, arguably, could have extended to the processing of artificial logographic characters, our findings suggest only that logographic-L1 users possess some superior visuo-spatial rehearsal capability in the visuo-spatial sketchpad and that bilingual experience can also provide some advantage on WM tasks.

It is conceivable that the experimental WM paradigm may not have been sensitive enough to detect logographic transfer effects, given that a bilingual advantage also existed. Importantly, on a carefully controlled L1 WM task, Chinese-English bilinguals had larger spans than the alphabetic-L1 speakers, supporting the idea that L1 orthographic variation affects processing in WM. That is, different orthographies require specific types of cognitive processing in WM. Because both sets of L1 language items were controlled for temporal word length, it is likely that the Chinese-English bilinguals were utilizing processes other than phonological rehearsal. The virtually identical L1 spans in alphabetic-L1 users suggest that they processed the L1 items (English) similarly. The superior L1 WM spans of the Chinese-English bilinguals is consistent with the proposed existence of a non-articulatory storage system associated with the recall of Chinese words in WM (e.g., Cheung & Kemper, 1993, 1994; Cheung et al., 2000). An L1 processing differential between Chinese and English language items supports the argument that variant orthographic systems require different types of cognitive processing.

A bilingual history was shown to provide positive performance benefits for L3 items but not for L1 recall. This finding begs the question if bilinguality per se affected L2 WM performance, why then were no bilingual effects detected on the L1 WM tasks? Previously, we posited that when processing the artificial logographs under the condition of concurrent visuo-spatial suppression (Experiment 1), the bilingual advantage resulted from superior executive control ability. That is, the bilinguals were better able to focus selectively on rehearsing items in one WM subsystem (the phonological loop) when deprived of access to the other (the visuo-spatial sketchpad). Others have shown a similar bilingual advantage on tasks requiring high levels of executive control (e.g., Bialystok, 1992, 1997, 1999). However, the task of recalling L1 words in WM was undertaken without any concurrent interference, thus requiring less executive control. No bilingual advantage emerged with the less demanding task.

It is also possible that the inculcation of an L1-logographic language may only result in the enhancement of specific types of visual processing skill. For example, Ehrich and Meuter (2009) showed that Chinese-English bilinguals outperformed the English bilingual and monolingual groups when recognising pre-learnt artificial logographs from structurally altered set of items, indicating a superiority of visual processing skills closely related to recognition. However, this visual processing advantage of the logographic background bilinguals only emerged in comparison with the monolinguals (using meaningful artificial logographs). It may be that L1-logographic processing skills are limited to cognitive processing involved in the recognition of the structural features of logographic items, not their storage and rehearsal in WM. This would explain why the Chinese-English bilinguals outperformed their alphabetic counterparts on a lexical decision task but not on tasks that required more extensive processing (such as judging the syntactic legality of a logographic string) (Ehrich & Meuter, 2009). Alternatively, given there was no effect of structural complexity, it may simply be that the structures used were not complex enough to reveal a logographic-L1 background advantage in WM. Logographic characters in Chinese can contain as many as 24 strokes (Shu et al., 2003) and, compared to the mere 26 characters in the alphabet, there are thousands of characters. Our task may not have allowed the Chinese-English bilinguals to demonstrate fully their specialised skills, also referred to by others (e.g., Hue & Erickson, 1988; Mou & Anderson, 1981; Zhang & Simon, 1985). Future research could consider increasing the logographic complexity of our artificial script to test this supposition.

Finally, evidence was found that the phonological loop played a significant role in the WM processing of an artificial logographic script but bilinguals were far less affected than monolinguals when phonological rehearsal was not possible. This finding is consistent with Baddeley's (1986, 1990, 2002) theory that the phonological loop plays a primary role in the processing of language in WM. Visuo-spatial rehearsal was much less efficient, however here too the bilinguals were at an advantage.

In conclusion, we have presented evidence that the inculcation of a logographic-L1 results in the enhancement of specialist orthographic processing skills in WM that can be transferred to the processing of an orthographically congruent language. While the data do not unequivocally support the idea that an enhanced visuo-spatial ability might account for some of the Chinese-English working memory

advantages, with few exceptions the logographic-L1 speakers had greater spans than the monolinguals and, when L1 and artificial logography performance were combined, also overall greater spans than their alphabetic-L1 bilingual counterparts. A bilingual background, quite independent of the languages used, appears to provide language learners with an advantage in working memory. These bilingual skills may be closely related to an ability to exert greater control and attention over executive functions related to WM. However, no bilingual performance benefits were evident when processing L1 items in WM (or indeed when processing artificial logographic L2 script without concurrent interference and with articulatory suppression). The use of an artificial logography is an innovative and promising avenue to explore language-specific processing skills in Chinese speakers. Future research could focus on a more complex artificial logography to tease out further the unique contributions of L1-specific processing skills in WM and language acquisition.

References

Akamatsu, N. (2003). The effects of first language orthographic features on second
      language reading in text. *Language Learning*, *53*(2), 207 – 231.

Ardila, A. (2003). Language representation and working memory with bilinguals.
      Journal of Communication Disorders, 36, 233 – 240.

Ardila, A., Rosselli, M., Ostrosky-Solis, F., Marcos, J., Granda, G., & Soto, M.
      (2000). Syntactic comprehension, verbal memory, and calculation abilities in
      Spanish-English bilinguals. *Applied Neuropsychology, 7*(1), 3 – 16.

Baddeley, A. D. (1966). Short-term memory for word sequence as a function of
      acoustic, semantic, and formal similarity. *Quarterly Journal of Experimental
      Psychology, 18*, 362 – 365.

Baddeley, A. D. (1986). *Working memory*. Oxford: Oxford University Press.

Baddeley, A. D. (1990). *Human memory: Theory and practice*. Boston: Allyn and
      Bacon.

Baddeley, A. D. (2002). Is working memory still working? *European Psychologist,
      7*(2), 85 – 97.

Baddeley, A. D., Gathercole, S., & Papagno, C. (1998). The phonological loop as a
      language learning device. *Psychological Review*, *105*(1), 158 – 173.

Baddeley, A. D., Thomson, N., & Buchanan, M. (1975). Word length and the
      structure of short-term memory. *Journal of Verbal Learning and Verbal
      Behaviour*, *14*, 575 – 589.

Bain, B., & Yu, A. (1978). Toward an integration of Piaget and Vygotsky: A
      crosscultural replication concerning cognitive consequences of bilinguality. In
      M. Paradis (Ed.), *Aspects of bilingualism* (pp. 113 – 126). Columbia, SC:
      Hornbeam.

Bialystok, E. (1987). Words as things: Development of word concept by bilingual
      children. *Studies in Second Language Learning, 9*, 133 – 140.

Bialystok, E. (1992). Selective attention in cognitive processing. In R. J. Harris (Ed.),
      Cognitive processing in bilinguals (pp. 501- 511). North-Holland: Elsevier
      Science Publishers.

Bialystok, E. (1997). Effects of bilingualism and biliteracy on children's emerging
      concepts of print. *Developmental Psychology, 33*, 429 – 440.

Bialystok, E. (1999). Cognitive complexity and attentional control in the bilingual

mind. *Child Development, 70*(3), 636 – 644.

Bialystok, E. (2007). Cognitive effects of Bilingualism: How linguistic experience leads to cognitive change. *The International Journal of Bilingual Education and Bilingualism, 10*(3), 210 – 223.

Bialystok, E., Craik, F. I., Klein, R., & Viswanathan, M. (2004). Bilingualism, aging, and cognitive control: Evidence from the Simon task. *Psychology and Aging, 19*(2), 290 – 303.

Campbell, R., & Sais, E. (1995). Accelerated metalinguistic (phonological) awareness in bilingual children. *British Journal of Developmental Psychology, 13*, 61 – 68.

Cenoz, J. (2000). Research on multilingual acquisition. In J. Cenoz & U. Jessner (Eds.), *English in Europe: The acquisition of a third language* (pp. 39 – 53). Clevedon: Multilingual Matters Ltd.

Cenoz, J., & Valencia, J. F. (1994). Additive trilingualism: Evidence from the Basque country. *Applied Psycholinguistics, 15*, 195 – 207.

Chen, Y., Fu, S., Iversen, S. D., Smith, S. M., & Matthews, P. M. (2002). Testing for dual brain processing routes in reading: A direct contrast of Chinese character and pinyin reading using fMRI. *Journal of Cognitive Neuroscience, 14*(7), 1088 - 1098.

Chen, H. -C., & Tsoi, K. C. (1990). Symbol-word interference in Chinese and English. *Acta Psychologica, 75*, 123 – 138.

Cheung, H. (1996). Nonword span as a unique predictor of second-language vocabulary learning. *Developmental Psychology, 32*(5), 867 – 873.

Cheung, H., & Kemper, S. (1993). Recall and articulation of English and Chinese words by Chinese-English bilinguals. *Memory and Cognition, 21*(5), 666 - 670.

Cheung, H., & Kemper, S. (1994). Recall and articulation of English and Chinese words under memory preload conditions. *Language and Speech, 37*(2), 147 – 161.

Cheung, H., Kemper, S., & Leung, E. (2000). A phonological account for the cross-language variation in working memory processing. *The Psychological Record, 50,* 373 – 386.

Chikamatsu, N. (1996). The effects of L1 orthography on L2 word recognition: A

study of American and Chinese learners of Japanese. *Studies in Second Language Acquisition, 18*(4), 403 – 432.

Chincotta, D., & Hoosain, R. (1995). Reading rate, articulatory suppression and bilingual digit span. *European Journal of Cognitive Psychology, 7*(2), 201 – 211.

Cimbalo, R. S., & Laughery, K. B. (1967). Short-term memory: Effects of auditory and visual similarity. *Psychonomic Science, 8*, 57 – 58.

Concise English-Chinese Chinese-English Dictionary (1999, 2nd Ed.). Oxford: Oxford University Press.

Cook, V. (1997). The consequences of bilingualism for cognitive processing. In A. M. B. de Groot & J. F. Kroll (Eds.), *Tutorials in bilingualism: Psycholinguistic persepectives* (pp. 279 – 301). New Jersey: Lawrence Erlbaum Associates.

Cummins, J. (1978). Metalinguistic development of children in bilingual education programs: Data from Irish and Canadian Ukrainian-English programs. In M. Paradis (Ed.), *Aspects of bilingualism* (pp. 127 – 138). Columbia, SC: Hornbeam.

Demetriou, A., Kui, Z. X., Spandoudis, G., Christou, C., Kyriakides, L., & Platsidou, M. (2005). The architecture, dynamics, and development of mental processing: Greek, Chinese, or Universal? *Intelligence, 33*, 109 – 141.

Ehrich, J. F., & Meuter, R. F. I. (2009). Acquiring an artificial logographic orthography: The beneficial effects of a logographic L1 background and bilinguality. *Journal of Cross-Cultural Psychology*, *40*(5), 711-745.

Ehrich, J. F., & Meuter, R. F. I. (2012, in preparation). *The influence of L1 and L2 on learning an artificial logographic orthography.*

Ehrich, J., Zhang, L., Mu, C., & Ehrich, L. (2012, in press). Are alphabetic-language derived models of L2 reading relevant to L1 logographic background readers? *Language Awareness*.

Ellis, N. C., & Sinclair, S. G. (1996). Working memory in the acquisition of vocabulary and syntax: Putting language in good order. *The Quarterly Journal of Experimental Psychology*, *49A*(1), 234 – 250.

Endo, Y. (1988). The role of motoric aspect of representation: spontaneous writing-like behaviour in Japanese. In M. M. Grunegerg, P. E. Morris, & R. N. Sykes (Eds.), *Practical aspects of memory: Current research and issues volume 2* (pp. 459 – 463). New York: John Wiley and Sons.

Flaherty, M. (2000). Memory in the deaf: A cross-cultural study in English and Japanese. *American Annals of the Deaf, 145*(3), 237 – 245.

Francis, W. N., & Kučera, H. (1982). *Frequency analysis of English usage: Lexicon and grammar.* Boston: Houghton Mifflin.

Gao, Y. J. (1983). Functions of phonetic radicals and other uses. *YuWen XuiXi (Language Studies), 9*, 53 – 55.

Hanley, J. R., & Huang, H. S. (1997). Phonological awareness and learning to read Chinese. In C. K. Leong & R. Malatesha Joshi (Eds.), *Cross-language studies of learning to read and spell: Phonologic and orthographic processing* (pp. 361 – 379). Dordrecht: Kluwer Academic Publishers.

Harrington, M., & Sawyer, M. (1992). L2 working memory capacity and L2 reading skill. *Studies in Second Language Acquisition, 14*, 25 – 38.

Hue, C., & Erickson, J. R. (1988). Short-term memory for Chinese characters and radicals. *Memory and Cognition*, *16*, 196 – 205.

Jessner, U. (1999). Metalinguistic awareness in multilinguals: Cognitive aspects of third language leaning. *Language Awareness, 8*(3), 201 – 209.

Jonides, J. (2000). Mechanisms of verbal working memory revealed by neuroimaging studies. In B. Landau, J. Sabini, J. Jonides, & E. Newport (Eds.), *Perception, cognition, and language: Essays in honor of Henry and Lila Gleitman* (pp. 87 – 105). Cambridge, Massachusetts: The MIT Press.

Juffs, A. (2004). Representation, processing and working memory in a second language. *Transactions of the Philological Society, 102*, 199 – 225.

Kimura, Y. (1984). Concurrent vocal interference: Its effects on Kana and Kanji. *Quarterly Journal of Experimental Psychology, 36A*, 117 – 131.

Klein, E. C. (1995). Second versus third language acquisition: Is there a difference? *Language Learning, 45*(3), 419 – 465.

Koda, K. (1999). Development of L2 intraword orthographic sensitivity and decoding skills. *The Modern Language Journal, 83*(1), 51 - 64.

Koda, K. (2000). Cross-linguistic variations in L2 morphological awareness. *Applied Psycholinguistics, 21*, 297 – 320.

Leung, Y. I. (2006). *L2 grammaticality and L2 working memory: Comparing Chinese-English and Spanish-English bilinguals*. Paper presented at the meeting of the Joint American and Canadian Association of Applied Linguistics, Montreal, Canada.

Luer, G., Becker, D., Lass, U., Yunqiu, F., Guopeng, C., & Zhongming, W. (1998). Memory span in German and Chinese: Evidence for the phonological loop. *European Psychologist*, *3*(2), 102 – 112.

Mann, V. A. (1985). A cross-linguistic perspective on the relation between temporary memory skills and early reading ability. *Remedial and Special Education*, *6*, 37 – 42.

Marcus, D. (1978). *A manual of Akkadian*. Lanham: University Press of America.

Mattingly, I. G. (1992). Linguistic awareness and orthographic form. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 11 – 26). Amsterdam: Elsevier Science Publishers.

Modern Chinese Frequency Dictionary. (1986). Beijing: Beijing Language Institute Press.

Mou, L. C., & Anderson, N. S. (1981). Graphemic and phonemic codings in short-term retention. *Bulletin of the Psychonomic Society, 17*(6), 255 – 258.

Muljani, D., Koda, K., & Moates, D. (1998). The development of word recognition in a second language. *Applied Psycholinguistics*, *19*, 99 – 113.

Papagno, C., Valentine, T., & Baddeley, A. D. (1991). Phonological short-term memory and foreign-language vocabulary learning. *Journal of Memory and Language*, *30*, 331 – 347.

Ransdell, S., Arecco, M. R., & Levy, C. M. (2001). Bilingual long-term working memory: The effects of working memory loads on writing quality and fluency. *Applied Psycholinguistics, 22*, 113 – 128.

Raven, J. C. (1962). *Advanced Progressive Matrices Set 2*. London: Lewis.

Rumiati, R. I., & Tessari, A. (2001). Initiation of novel and well-known actions: The role of short-term memory. *Experimental Brain Research, 142*, 425 – 433.

Salkind, N. J., Kojima, H., & Zelniker, T. (1978). Cognitive tempo in American, Japanese and Israeli children. *Child Development, 49*, 1024 – 1027.

Sasaki, M. (1987). Why do Japanese write characters in space?" *International Journal of Behavioral Development, 10*(2), 135 – 149.

Schneider, W., Eschman, A., & Zucchoiotto, A. (2001). *E-Prime User's Guide*. Pittsburgh: Psychology Software Tools, Inc.

Segalowitz, N., & Frenkiel-Fishman, S. (2005). Attention control and ability level in a complex cognitive skill: Attention shifting and second language proficiency. *Memory and Cognition, 33*(4), 644 – 653.

Service, E., Simola, M., Metsanheimo, O., & Maury, S. (2002). Bilingual working memory span is affected by language skill. *European Journal of Cognitive Psychology, 14*(3), 383 – 408.

Shu, H., Chen, X., Anderson, R. C., Wu N., & Xuan, Y. (2003). Properties of school Chinese: Implications for learning to read. *Child Development, 74*(1), 27 – 47.

Siegel, S., & Castellan, N. J. (1988). *Non-parametric statistics for the behavioral Sciences* (2nd ed). New York: McGraw-Hill Book Company.

Stevenson, H. W., & Lee, S.Y. (1990). Contexts of achievement: A study of American, Chinese and Japanese children. *Monographs of the Society for Research in Child Development, 55*(1 – 2), 1 -107.

Stigler, J. W., Lee, S.Y., & Stevenson, H. W. (1986). Digit memory in Chinese and English: Evidence for a temporarily limited store. *Cognition*, *23*, 1 – 20.

Tan, L. H., Liu, H. L., Perfetti, C. A., Spinks, J. A., Fox, P. T., & Gao, J. H. (2001). The neural system underlying Chinese logograph reading. *NeuroImage, 13*, 836 – 846.

Tavassolli, N. T. (2002). Spatial memory for Chinese and English. *Journal of Cross-Cultural Psychology, 33*(4), 415 – 431.

Thomas, J. (1988). The role played by metalinguistic awareness in second and third language learning. *Journal of Multilingual and Multicultural Development, 9*(3), 235 - 246.

Van den Noort, M. W. M. L., Bosch, P., & Hugdahl, K. (2006). Foreign language proficiency and working memory capacity. *European Psychologist, 11*(4), 289 – 296.

Williams, P. (1999). Memory, attention and inductive learning. *Second Language Acquisition*, *21*, 1 – 48.

Yamaguchi, S., Toyoda, G., Xu, J., Kobayashi, S., & Henik, A. (2002). Electroencephalographic activity in a flanker interference task using Japanese orthography. *Journal of Cognitive Neuroscience, 14*(7), 971 - 979.

Zhang, G., & Simon, H. A. (1985). STM capacity for Chinese words and idioms: Chunking and acoustical loop hypothesis. *Memory and Cognition, 13*(3), 193 - 201.

Figure 1. The artificial logographs and their corresponding meaning associations in Chinese (with tonal pronunciation) and English (Experiment 1).
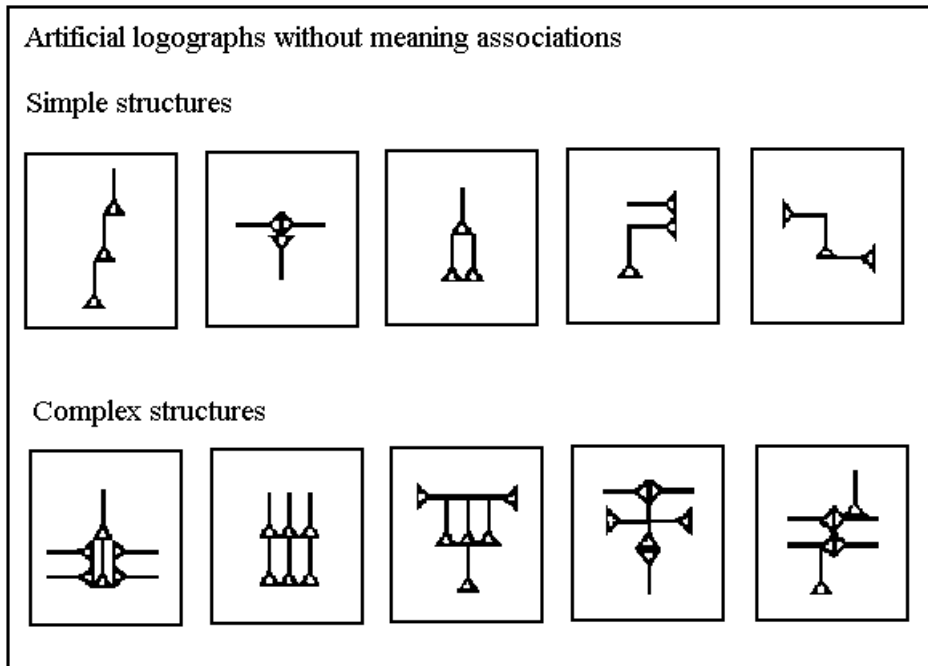
Figure 2. The 10 new artificial logograph structures (without meaning associations) (Experiment 2).

Table 1

Adjusted Mean WM Spans (with SE in brackets) for Artificial Logographs for the Logographic-L1 (Chinese-English Bilinguals) and Alphabetic-L1 (English-French Bilingual and English Monolingual) Background Groups for Serial Recall without Suppression (Normal) and with Articulatory and Visuo-Spatial Suppression (Supp)

L1 Background	Logographic	Alphabetic	
Group	Bilingual	Bilingual	Monolingual
WM Tasks			
Normal	3.7 (0.3)	3.3 (0.3)	3.2 (0.3)
Articulatory Supp	2.8 (0.2)	2.2 (0.3)	1.6 (0.2)
Visuo-Spatial Supp	3.5 (0.3)	3.1 (0.4)	1.7 (0.3)

Table 2

Adjusted mean memory spans (with SE in brackets) for L1 words (L1 Span), and for meaningless and meaningful artificial logographs for the Logographic-L1 (Chinese-English Bilinguals) and Alphabetic-L1 (English-French Bilingual and English Monolingual) Background Groups

L1 Background	Logographic	Alphabetic	
Span	Bilingual	Bilingual	Monolingual
L1	5.4 (0.3)	3.9 (0.3)	4.2 (0.2)
Artificial Logography			
Meaningless	3.9 (0.4)	2.8 (0.5)	2.3 (0.4)
Meaningful	3.7 (0.3)	3.3 (0.3)	3.2 (0.3)
Mean span	3.8 (0.3)	3.0 (0.4)	2.7 (0.3)

Appendix 1

Table 1

Age of L2 Acquisition and Time Spent in an L2 Environment (in years) for Chinese-English and English-French Bilinguals (in Terms of Number of Individuals in each Category)

Age of L2 Acquisition	Bilinguals	
	Chinese-English	English-French
1-3	0	2
3-6	0	2
7-12	5	3
13-18	11	4
>18	1	2
Total	17	13
Time in L2 Environment		
< 1*	1	3
1-3	6	4
3-6	7	1
6-10	2	2
>10	1	3
Total	17	13

Note. * Participants in this category had spent at least 6 months in an L2 environment but less than 1 full year.

Appendix 2

Table 1

English and Chinese Temporal Word Length in Milliseconds (SDs in parentheses)

English	Temporal Word Length	Chinese	Temporal Word Length
Village	637	村子	503
Policeman	633	警察	646
Reporter	624	记者	557
Insect	692	昆虫	616
Movie	525	电影	538
Ocean	486	海洋	595
Vehicle	551	车辆	536
Weapon	458	武器	565
Student	637	学生	601
Teacher	493	教师	624
Mean	574 (81)		578 (46)

Footnotes

[1] Chinese characters have semantic and phonetic radicals that can be used to access pronunciations. However, accessing pronunciation from Chinese script in this manner is irregular (Shu et al., 2003).

[2] A one-way ANOVA indicated no group difference in the time taken to acquire the artificial logographic script, $F < 1$, suggesting also no difference in intrinsic motivation to acquire the stimuli.

[3] The choice of articulation phrase is widely considered to be unimportant (Baddeley, 1990). Furthermore, studies have shown that the language of the suppression phrase does not affect WM recall (e.g., Chincotta & Hoosain, 1995). However, *Coca Cola* was chosen because it is a well-known phrase and has been used in prior WM studies (see Baddeley, 1986).