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The Effect of Orthography on Visuospatial Abilities: A Comparison of Chinese and English

by

Riley Swab

Dr. Yun Kim
Adviser

Emory University's Program of Linguistics

Dr. Yun Kim

Adviser

Dr. Hong Li

Committee Member

Dr. Phillip Wolff

Committee Member

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How Orthography Impacts Visuo-Spatial Working Memory: A Correlational Study of Chinese and English

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Riley Swab

Dr. Yun Kim

Adviser

An abstract of
a thesis submitted to the Faculty of Emory College of Arts and Sciences
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Abstract

How Orthography Impacts Visuo-Spatial Working Memory: A Correlational Study of Chinese and English
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The current study seeks to examine if orthographies impact the visuo-spatial abilities in working memory. The two orthographies studied were English, which is an alphabetic orthography, and Mandarin Chinese, which is a logographic orthography. In addition to studying native adult speakers for both languages, we also studied college students in their first level of a Chinese language class at Emory University to see if learning a more visually demanding orthography would alter their visuo-spatial abilities.

Based on previous research, our study had two hypotheses. The first hypothesis is that native Chinese speakers would perform the test both faster and more accurately than their native English counterparts. The second hypothesis is that the Chinese second language learners would perform faster and more accurately on the visual discrimination portion of the test than the native English speakers, but otherwise would show no noticeable difference from the native English speakers' performance. Our study adapted Gardner's (1996) Test of Visual Perceptual Skills-4$^{th}$ edition (TVPS-4) to a computer-based task, otherwise keeping the layout the same. 6 items, out of a total of 18, were chosen for each of the 7 sections.

The data revealed a significant group effect on accuracy for sequential memory, ($F$ (3.88) =4.67, $p$=0.32), but not for any of the other sections. Furthermore, the data revealed a significant group effect on the time spent on sequential memory, ($F$ (3.88) =4.49, $p$=.035), but not for any of the other sections. Further analysis showed that the one-way ANOVA for the total TVPS-4 found significant effect of group on accuracy, but not for time.

The data does not support our second hypothesis, but instead provides evidence to suggest that the difference is between native English and native Chinese, and native English and Chinese second language learners for sequential memory. Overall, our first hypothesis is supported with native English participants performing significantly less accurate overall, although the time results were not significant.

This research suggests that there is a difference in visual-spatial working memory depending on orthography and suggests that learning a different orthography may impact your visuo-spatial abilities. Further research is needed to assess the extent of this impact.

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# How Orthography Impacts Visuo-Spatial Working Memory: A Correlational Study of Chinese and English

Previous research has investigated the link between reading acquisition and a language's writing system or visuo-spatial working memory, but there has been limited research on the relationship between a language's writing system and visuo-spatial working memory (Liu, Chen, & Chung, 2015; Liu, Chen & Wang, 2016; Vellutino, et al., 2007). There, however, has been little research about how a language's writing system, or orthography, can impact cognitive abilities, such as working memory. The relationship between working memory and orthography could imply that knowledge of a language has a deeper impact on cognitive functions than simply existing as a means of communication.

The proposed study examined how two different orthographies impact the visuo-spatial portion of working memory by comparing native English speakers and native Mandarin Chinese speakers. We also tested second language learners of Chinese to see if learning a new, more visually demanding, orthography would alter visuo-spatial working memory.

Based on previous research, the current study has two main hypotheses. The first hypothesis is that native Chinese speakers will perform the test both faster and more accurately than their native English counterparts. The second hypothesis is that the Chinese second language learners will perform faster and more accurately on the visual discrimination portion of the test than the native English speakers but otherwise will show no noticeable difference from the native English speakers' performance.

**Visuo-Spatial Working Memory**

Working memory's function and structure have been a relatively recent discovery in psychology, although there have been frequent improvements in our understanding of working memory. In 1960, Miller and colleagues created the first model of working memory, which they labeled as the temporary storage and manipulator of the necessary information for various complex cognitive activities (ctd. In Baddeley, 2003, page 189).

In 1974, however, Baddeley and Hitch extended this one-component model into the three-component system still used today (Cole & Pickering, 2010). The first component identified in this system is the central executive portion, which controls attention and consolidates the other components' information (Cole & Pickering, 2010). The phonological loop is the portion of working memory that is responsible for both acoustic and verbal information (Cole & Pickering, 2010).

The component of working memory that the current research is interested in is the visuo-spatial sketchpad. The visuo-spatial sketchpad stores both visual and spatial information and then integrates the visual and spatial representations by creating an interface between them (Baddeley, 2002). This integration of information allows the visual and spatial information to be both stored in long-term memory and be accessed through the senses (Baddeley, 2002).

Although working memory is apparent in everyone, regardless of language, there have been previous studies that explore the differences that native language has on working memory. For example, there has been a growing interest in how the phonological and visual components of working memory interact during word recognition for speakers of logographic scripts and how that interaction differs for speakers of alphabetic scripts (Smythe et al., 2003; Cole & Pickering, 2010).

To help explain why different orthographies use different portions of working memory, Chen and Juola (1982) created the orthographic variation hypothesis. Under the orthographic variation hypothesis, different orthographies activate different word processing mechanisms, which then emphasize varying areas of working memory differently (Chen & Juola, 1982).

**Chinese and English Orthographies**

Every language has a specific orthography, of which there are three main types. Of the two languages we are studying, Chinese is typically defined as a logographic orthography, although some propose a different orthographic style, which will be discussed further on, while English is an alphabetic orthography.

A logographic orthography uses symbols to represent an entire word or concept (Cole & Pickering, 2010; Perfetti, Liu, Fiez, et al., 2007; Wang, Koda, & Perfetti, 2003). Although most research categorizes Chinese as a logographic orthography, some researchers have instead labeled Chinese as a combination of a logographic and morpho-syllabic orthography. A morpho-syllabic orthography is when the morpheme represents a spoken syllable (Perfetti, Liu, Fiez, et al., 2007). English, on the other hand, uses an alphabetic orthography, in which symbols represent individual sounds, or phonemes (Cole & Pickering, 2010).

Because learning Chinese requires the acquisition of specific character forms rather than generalized decoding procedures, the character forms, which are the visual-spatial layouts of strokes and radicals, plays a crucial role in learning to read (Tan, Spinks, et al., 2005; Perfetti, Liu, Fiez, et al., 2007). This emphasis on character forms and visual information is not seen to this extent in the reading of alphabetic scripts (Perfetti, Liu, Fiez, et al., 2007).

Previous research on the amount of spatial memory usage needed while reading Chinese has shown that learning to read Chinese depends more on making appropriate visual distinctions between characters than it does on phonological skills (Wang, Koda, et al., 2003). One explanation for this is that because Chinese characters are arranged in a non-linear pattern and have a high spatial frequency there are more demands on spatial memory compared to the linear arrangement an alphabetic script would demand (Wang, Koda, et al., 2003). Regardless of age, beginning readers of visually more complex orthographies, like Chinese, demonstrate more advanced visual skill than beginning readers of visually simpler orthographies, like English (Zhou, Aram, & Tolchinsky, 2011).

Chinese and English were chosen as the target languages because, through previous research, it has been suggested that the structure of their orthography's contrasts with each other in a variety of areas. Perfetti (1999) found evidence to suggest that Chinese presents the highest contrast to alphabetic systems because its graphic forms and spatial configurations highly contrast with the linear structure of most alphabetic languages.

One such difference between Chinese and English orthographies is in the skills used in learning to read each language. Previous research on the amount of visual memory needed while reading Chinese suggests that learning to read Chinese depends more on making appropriate visual distinctions between characters than it does on phonological skills (Wang, Koda, et al., 2003). English, however, relies more on phonological skills in learning to read English. One reason for this difference is because Chinese characters are arranged in a non-linear pattern, as compared to the linear arrangement of alphabetic orthographies, so it requires a larger demand on spatial memory (Wang, Koda, et al., 2003).

In addition, the basic knowledge required of speakers in both languages to be considered proficient speakers is vastly different. English relies on 26 letters from the Roman alphabet, which can be combined in an infinite number of ways to create words (Daniels & Bright, 1996). Chinese, however, contains up to 40,000 distinct characters, with knowledge of approximately 2,500 characters required to read a standard newspaper (Dehaene, 2009).

Shu colleagues (2003) examined how students in mainland China are taught characters in their first six elementary school years. They found that the students learned on average 2,570 distinct characters over these six years (Shu et al., 2003). Furthermore, they found that the most prominent dimensions the teachings of those characters were based on were the visual complexity of the characters, the spatial structure of the components of the characters that provide the information on their meaning, and the semantic transparency of the character (Shu et al., 2003). These dimensions suggest that the process of learning Chinese builds complex, individual, visuo-spatial skills and strategies that encompass perception, memory, and reasoning (Shu et al., 2003).

Because of their distinct writing systems, Chinese and English also differ in regularity and predictability. In Chinese, morphemes can be combined in regular and predictable ways to form new concepts, while in English it is much more difficult to do so (McBride-Chang, Cho, et al., 2005). For example, although the English words *woman (女人)* and *adult(成人)* are morphologically unrelated to each other, in Mandarin Chinese, these terms share the base morpheme of *ren2*, meaning person (McBride-Chang, Cho, et al., 2005). This regularity in Chinese may lead to Chinese children focusing more on patterns of association and categories earlier and more systematically than English children (McBride-Chang, Cho, et al., 2005).

Chinese is, however, less regular in its sound to print mapping, meaning the visual cues are the main way that readers differentiate between characters (McBride-Chang, Chow, et al., 2005). These visual cues tend to be the individual strokes of each character, with the space the character occupies being constant (McBride-Chang, Chow, et al., 2005). English readers, meanwhile, tend to use the word length, or the space the word occupies, as the visual cue in reading (McBride-Chang, Chow, et al., 2005).

Overall, prior research has suggested that visual-orthographic skills may be more crucial to learning to read Chinese than to learning to read alphabetic orthographies (Leck, Weekes, & Chen, 1995). These studies and findings led to the current study's decision to compare Chinese and English orthographies on their impact on visuo-spatial working memory ability.

**Prior Research on Native Chinese Speakers**

Prior research has sought to compare adult native Chinese speakers to adult native English speakers to examine a variety of different abilities, ranging from processing strategies to visual coding. Much of this research, however, has focused on how speakers of Chinese and English access and process visual information, not so much on specific abilities of visuo-spatial working memory.

Biederman and Tsao (1979) administered a Stroop task to sixteen native Chinese speaking college students, who were also bilingual in English, and sixteen native English-speaking college students. The two groups were administered the same task, although the Chinese participants were told instructions in Chinese and responded in Chinese, while the English participants were told instructions in English and responded in English (Biederman & Tsao, 1979).

Their results found that the Chinese participants performed slower and with a slightly higher error rate on the color naming of the word than the English-speaking participants (Biederman & Tsao, 1979). Furthermore, they found that the magnitude of the Stroop interference effect was greater with the Chinese participants than the English participants, suggesting the different orthographies activate different processing strategies (Biederman & Tsao, 1979). Biederman and Tsao (1979) suggested that this result could be because the Chinese orthography permits more direct access to the meaning and image of the word in memory than the English orthography.

Like Biederman and Tsao (1979), Chen and Juola (1982) studied 24 Chinese speakers and 24 English speakers. They, however, were interested in whether different orthographic systems affect visual coding and memory differently (Chen & Juola, 1982). They gave participants a list of words from pairs of graphemically, phonemically, and semantically similar words and told the participants to study the list (Chen & Juola, 1982). The other members of each pair on the list were used in the recognition task, in which subjects were asked to decide if the word matched the word they had previously studied in either appearance, sound, or meaning (Chen & Juola, 1982). They repeated this test both immediately and 24-hours later (Chen & Juola, 1982).

Chen and Juola (1982) found that for the Chinese participants, the responses for the graphemic decisions were more accurate than both the semantic and phonemic decision responses, while for the English participants there was no significant result. Furthermore, they found that the response times for the Chinese subjects was the shortest for graphemic decisions, while the English subjects were the slowest for the graphemic decisions (Chen & Juola, 1982). What this suggests is that the Chinese participants were more attuned to the visual representation of the words, as compared to the meaning or sound, which could indicate greater visuo-spatial abilities for working memory.

Wang, Koda, and Perfetti's (2003) study involved a different population than both the previous studies and the current study, although it did involve native Chinese speakers. Wang, Koda, and Perfetti (2003) examined the cognitive consequences of alphabetic versus nonalphabetic first language literacy experiences for learning an alphabetic second language. The alphabetic language they studied was Korean, while the nonalphabetic language was Chinese. They gave a semantic category judgment task and a phoneme deletion task to 20 native Chinese ESL students and 20 native Korean ESL students (Wang, Koda, & Perfetti, 2003).

Their results found that the native Chinese readers were more attentive to orthographic information than the Korean subjects (Wang, Koda, & Perfetti, 2003). Furthermore, the Chinese subjects demonstrated more sensitivity to orthographic similarity and had more difficulty manipulating sounds in the English words than the Korean subjects (Wang, Koda, & Perfetti, 2003). Overall, the Chinese subjects had a poorer performance than the Korean subjects in both the tasks, as well as slower responses in the category judgment task (Wang, Koda, & Perfetti, 2003). This supports prior evidence that an alphabetic L1 facilitates word identification in an alphabetic L2, compared to a logographic L1 (Muljani, Koda, & Moates, 1998). In the current study, we are examining the reverse situation, in which participants have an alphabetic L1 but are learning a logographic L2 instead of an alphabetic L2.

**Prior Research on Second Language Learners of Chinese**

In addition to studying native speakers of both Chinese and English, the current study is also interested in second language learners of Chinese. We are particularly interested in if knowledge of a new orthography can impact visuo-spatial working memory. In addition to having a different native language, Chinese second language learners are also different from native Chinese speakers because they must learn to speak and read simultaneously, which might force them to rely more on the visual form of words to access the lexicon than the native speakers (Wang, Perfetti, & Liu, 2003).

Previous research on adults learning Chinese as a second language has sought to examine how they navigate the visual workload of the Chinese orthography (Perfetti, Liu, Fiez, et al., 2007; Wang, Perfetti, et al., 2003; Kim, 2010). Perfetti, Liu, Fiez, and colleagues (2007) and Wang, Perfetti and colleagues (2003) studied adult English speakers learning Chinese as a foreign language. They found that although learning to read Chinese requires learners to accommodate visual workload, that skill is less important when reading alphabetic orthographies (Perfetti, Liu, Fiez, et al., 2007; Wang, Perfetti, et al., 2003). Kim (2010), meanwhile, found that adult Chinese second language learners tend to bypass the visual stage of character acquisition, possibly because their visuo-spatial skills are not skilled enough to comprehend at this stage.

Wang, Perfetti, and Liu (2003), also studied adult second language learners but examined visual-orthographic sensitivity in the participant's processing of Chinese characters. They gave 15 participants in a first-year Chinese language program at either the University of Pittsburgh or Carnegie Mellon University a lexical decision task, a naming task, and an onset, rime, and tone matching task (Wang, Perfetti, & Liu, 2003).

Their results found strong evidence for early visual-orthographic sensitivity in the lexical processing of Chinese characters in the participants with an alphabetic background (Wang, Perfetti, & Liu, 2003). The participants showed sensitivity to the structural complexity of the characters, with a faster and more accurate performance when exposed to simple characters than when exposed to compound characters (Wang, Perfetti, & Liu, 2003). This could potentially indicate that although they recognize the visual structure of the characters, their visual skills are not practiced enough to process the compound characters.

Overall, their results suggest that beginning Chinese learners who are already skilled in an alphabetic system demonstrate early visual-orthographic sensitivity in the lexical processing of Chinese characters and early sensitivity to the structural complexity and compositional relationship of the characters (Wang, Perfetti, & Liu, 2003).

Zhou and McBride (2018) studied native Chinese and Chinese second language learning children from the same dual Chinese-English learning environment. They found that pure visual skills did not contribute to Chinese word reading in native Chinese speakers but had a significant role in word reading of non-native Chinese speaking children (Zhou & McBride, 2018). The Chinese second language learners and native Chinese speakers, however, performed comparatively on tests of pure visual skills (Zhou & McBride, 2018).

Regardless of age and language, previous research has indicated that visual skills are important in early reading development, which could contribute to an increased visuo-spatial working memory ability in second language learners at the beginning level (Corcos et al., 1993).

**Gardner's Test of Visual Perceptual Skills**

The test that is being administered in the current study is the *Test of Visual Perceptual Skills (4th ed.)* (TVPS-4), which was created by Gardner in 1996 ("Test of Visual Perceptual Skills-4," 2017). The TVPS-4 assesses two-dimensional visual-perceptual skills ("Test of Visual Perceptual Skills-4," 2017). According to the TVPS-4, visual perceptual skills are defined as those skills that provide information about the objects, events and spatial layout in a manner that allows the person to think and act according to the information provided ("Test of Visual Perceptual Skills-4," 2017). Specifically mentioned under these skills is the ability to identify important visual features in the environment and integrate the visual information with other sensory systems, both of which are key components of the visuospatial sketchpad in working memory ("Test of Visual Perceptual Skills-4," 2017).

The TVPS-4 consists of seven distinct sections, based on Scheiman's (2011) Model of Visual Information Processing ("Test of Visual Perceptual Skills-4," 2017). The visual discrimination section tests the participant's "ability to discriminate dominant features of objects”; the visual figure-ground section tests the participant’s “ability to identify an object or particular features of an image within a complex background”; the visual closure section tests the participant’s “ability to identify a form or image when only some” part of the image is present; the visual memory section tests the participant’s “ability to recognize and recall visually presented information”; the spatial relationships sections tests the participant’s “ability to recognize the positioning of objects”; the form constancy section tests the participant’s “ability to perceive the positional aspect[s] [of objects] and recognize objects when they are in a different orientation or format”; the sequential memory section tests the participant’s “ability remember forms and sequences of forms and recognize them quickly when seen again” (“Test of Visual Perceptual Skills-4,” 2017; Bugaiski, 2017).

Tolchinsky, Levin, and colleagues (2012) used the visual discrimination section from the TVPS to examine how the visual-spatial relationships in native Spanish, Hebrew, and Cantonese 5-year-olds explained their literacy skills. Although the current study studied adult Mandarin Chinese speakers and was interested in visual-spatial working memory, not literacy skills, this study was influential in its use of the TVPS visual discrimination section and the results it obtained. Their results found that the Cantonese speakers significantly outperformed the Spanish and Hebrew speakers on the test of visual discrimination (Tolchinsky, Levin, et al., 2012). This result was attributed to the training effect that character learning has on the development of visual skills of Cantonese speakers (McBride-Chang, Zhou, et al., 2011; Tolchinsky, Levin, et al., 2012).

## Method

### Participants

This study's sample was made up of 15 undergraduate students from Emory University (18-24 years old, $M_{age}$=20, SD= 1.6). The participants were divided into three groups. The first group was native English speakers. The second group was native Chinese speakers. The third group was level 100 Chinese second language learners.

The first group had 5 participants ($M_{age}$=20.14). Although they all were native English speakers, they all also reported knowing other languages, such as Spanish, Serbian, French, and Arabic. The second group had 5 participants ($M_{age}$=19.4). All the participants were native Mandarin Chinese speakers, although they all reported knowing English for more than 13 years and using English most of the time. In addition, they reported knowing Japanese, Spanish, and French. The third group had 5 participants ($M_{age}$=19.8). 3 of the participants spoke two languages, and only two of the participants only spoke English. Two of the participants also spoke Korean, while the other participant also spoke Spanish.

Participants were recruited via flyers and through word of mouth using convenience sampling procedures. Each participant signed the consent form before participating in the study.

### Measures

**Language Background.** Before taking the visuo-spatial portion of the study, participants completed an online language survey. Participants self-reported their age, amount of languages known, and what language class they are currently in if they are in one (Appendix A). Participants were then instructed to provide when they began learning the language, how many years they have studied or used it, in what setting they learned the language, and how much they use that language for each language they indicated they knew. This questionnaire was created by the researchers for this study. This measure represented the dependent variable.

**Test of Visual Perceptual Skills Test.** Gardner's Test of Visual Perceptual Skills version 4 (TVPS-4) was adapted to a computer-based test using the program Psychopy (see Appendix B for an example flow). To adapt and make the test more accessible for participants, the number of questions for each section was reduced from 18 to 6 for each of the seven sections. The images were kept as black and white images, to be consistent with the original test.

To adapt the test to a computer-based test, the images were recreated using Windows Paint and then exported to Psychopy. The layout of each section was kept the same to keep reliability and validity comparable. Before each section began, the instructions as listed on the original test were shown, followed by one example, and then the instructions again to ensure that the participant understood the directions. Instead of the participant pointing or verbally saying which choice they chose as the answer, the participant was instructed to press the number on the keyboard corresponding to their answer choice.

The test otherwise followed the instructions listed on the original test. For example, since all the participants were over 12 years old, the first three items on the test were exempted from the computer adaptation. An example of a test item from the original test and the adapted test can be found in Appendix C. Accuracy was coded for 1 if the participant chose the correct answer and 0 if the participant chose the incorrect answer, with a maximum score of 6 for each section and a minimum score of 0 for each section. Tables 1 and 2 show the means, sums, and variances for accuracy and time (sec.) for the total TVPS-4 and the seven TVPS-4 sections for each language group.

The test included seven different sections that each tested a different skill. The seven sections are visual discrimination, visual memory, spatial relations, form constancy, sequential memory, figure-ground, and visual closure. In the visual discrimination task, participants were asked to find the one image, in a field of five similar images, that exactly matched the presented target image. In the visual memory task, participants were presented with a target image for five seconds and were asked to remember that image and then find the image, in a field of four images, on the subsequent slide. In the spatial relationships task, participants were asked to find the one image, in a field of five images, that was different from the rest.

In the form constancy task, participants were asked to find the one image, in a field of four or five images, that matched the presented target, with the matching image being larger, smaller, rotated and/or embedded within a larger design. In the sequential memory task, participants were presented with an image of a sequence of elements for five seconds and were asked to remember it and then find the image with the same sequence, in a field of four images, on the subsequent slide. In the visual figure-ground task, participants were asked to find a target image that was embedded in one of a field of four complex designs. In the visual closure task, participants were asked to match an incomplete target image to the correctly completed image in a field of four. Each of the sections' questions progressed in difficulty as the participant progressed through the section.

The original TVPS-4 has an overall Alpha Cronbach of .94, showing that the measure is reliable ("Test of Visual Perceptual Skills-4," 2017). To analyze the results, we looked at the rate of time each participant took to complete the test, in addition to the accuracy of their test results. The accuracy and rate of time represented the independent variables of the study.

**Word Recall Task**. Participants also completed a word recall task, which consisted of fifteen words viewed for one second each word. Afterward, participants were asked to write down as many of the words that they could remember as possible. The amount of words the participants correctly identified was used in analysis, with the maximum amount a participant could report being fifteen. This was randomly given either before or after the TVPS-4, to account for timing and fatigue effects.

## Procedure

Undergraduate Emory students were recruited via convenience sampling using flyers and word of mouth. Participants had read and signed an informed consent form before the study began. The study then began with an approximately 5-minute language background survey. Following that was an approximately 20-minute computer-based test consisting of visual stimuli. The visual skills test was adapted from Gardner's Test of Visual Perceptual Skills version 4, which consisted of seven sections on paper. Before completing the TVPS-4, participants were told how to work the program, namely that to submit their answer they had to press the number corresponding to their choice on the keyboard. Participants then self-paced themselves through the test, taking breaks between sections if need be. Before participants arrived, it was randomly decided when they were taking the word recall test, either before or after the TVPS-4.

## Design

The current study was a within-subjects study with three distinct groups: native English, native Chinese, and Chinese second language learners. The independent variables were accuracy and time, while the dependent variable was represented by their language group. Other variables taken into consideration were other languages known by participants in addition to English and Chinese.

# Results

## Accuracy

**Table 1**

*Means and Standard Deviations of Accuracy for Total TVPS-4 and TVPS-4 Sections*

| | Native Chinese (n=5) | | Native English (n=5) | | Chinese L2 (n=5) | |
|---|---|---|---|---|---|---|
| Test | *M* | *SD* | *M* | *SD* | *M* | *SD* |
| TVPS-4 Total | 25.143 | 3.976 | 20.857 | 4.099 | 25.429 | 2.82 |
| Visual Discrimination | 5.2 | 0.837 | 4 | 1 | 5 | 0 |
| Visual Memory | 4.6 | 0.548 | 4.6 | 0.547 | 5 | 1.225 |
| Spatial Relations | 5.8 | 0.447 | 4.8 | 1.304 | 5.8 | 0.447 |
| Form Constancy | 3.8 | 0.837 | 2.4 | 0.894 | 4.2 | 1.924 |
| Sequential Memory | 6 | 0 | 4.4 | 1.14 | 5.4 | 0.894 |
| Figure-Ground | 5.4 | 0.894 | 4.4 | 1.14 | 5.6 | 0.548 |
| Visual Closure | 4.4 | 0.548 | 4.6 | 0.548 | 4.6 | 0.548 |

*Note.* L2 stands for Second Language Learner

Table 1 shows the means and standard deviations for accuracy for the total TVPS-4 and the seven TVPS-4 sections for each language group. Overall, the native Chinese group and the Chinese L2 group show a similar pattern in that both groups outperformed the English group on accuracy. To determine whether these differences are statistically significant or not, a one-way ANOVA (Accuracy X Group) for the total TVPS-4 was conducted.

**Figure 1**

*Average Accuracy for Total TVPS-4*

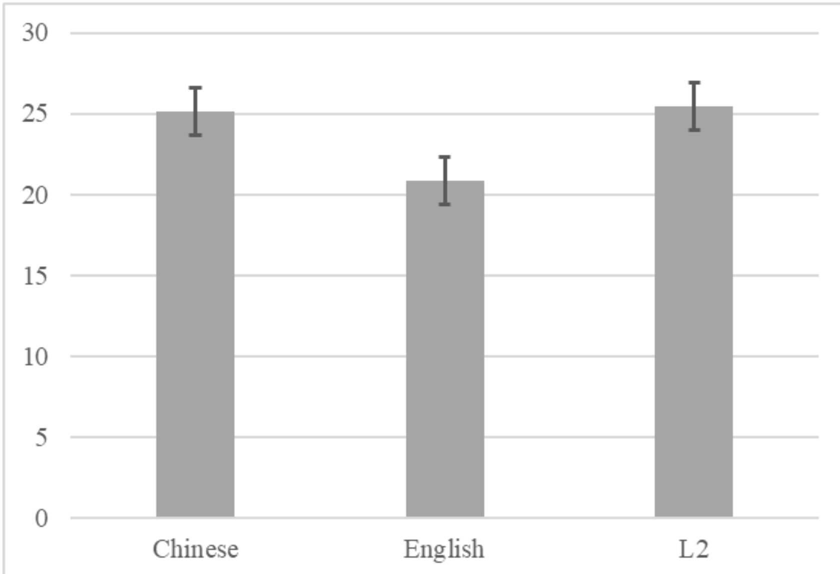


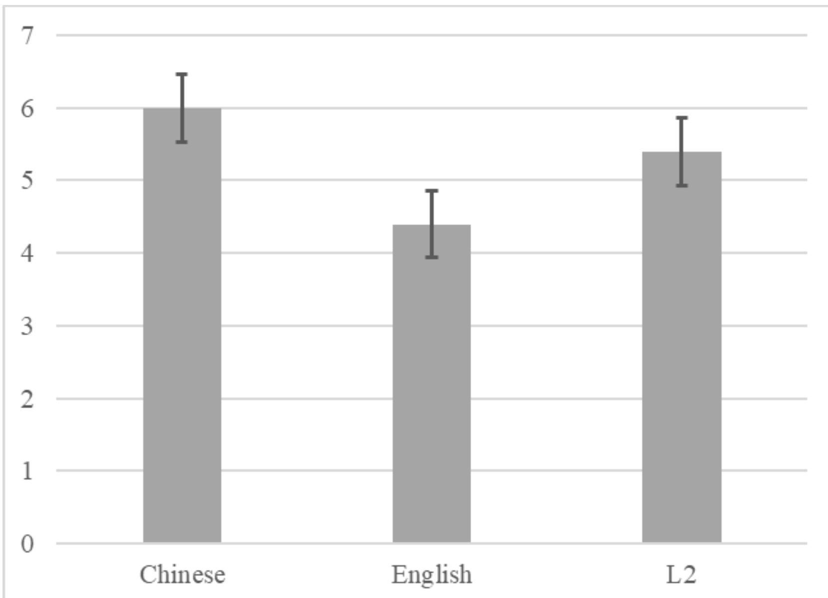

Figure 1 shows that a significant effect of group on accuracy was found (*F* (3.39) =3.55, *p*=.056). A post-hoc t-test was performed to analyze the if differences existed between the groups. The t-test found a significant difference between the total accuracy of the native English group and the Chinese L2 group (*p*=.032), with the Chinese L2 group performing more accurately than the native English group. There were no significant differences found between the native Chinese group and the native English group (*p*=.070) and between the native Chinese group and the Chinese L2 group (*p*=.88).

To further test whether these group differences are shown in all sections, we performed one-way ANOVAS for accuracy (Accuracy X Group) for each of the seven sections. Out of the seven sections, a significant group effect was only found for Section 5, Sequential Memory, (*F* (3.88) = 4.67, *p*=.032) (Figure 2). The results supported the hypothesis that the population means between the native Chinese group and the native English group were different (*p*=.014), but did not support the hypotheses that the population means between the native Chinese group and the

Chinese L2 group were different (*p*=.172) or between the native English group and the Chinese L2 group were different (*p*=.161). The t-test results showed that the native Chinese group performed more accurately than the native English group.

**Figure 2**

*Average Accuracy for Section 5, Sequential Memory*



**Time**

**Table 2**

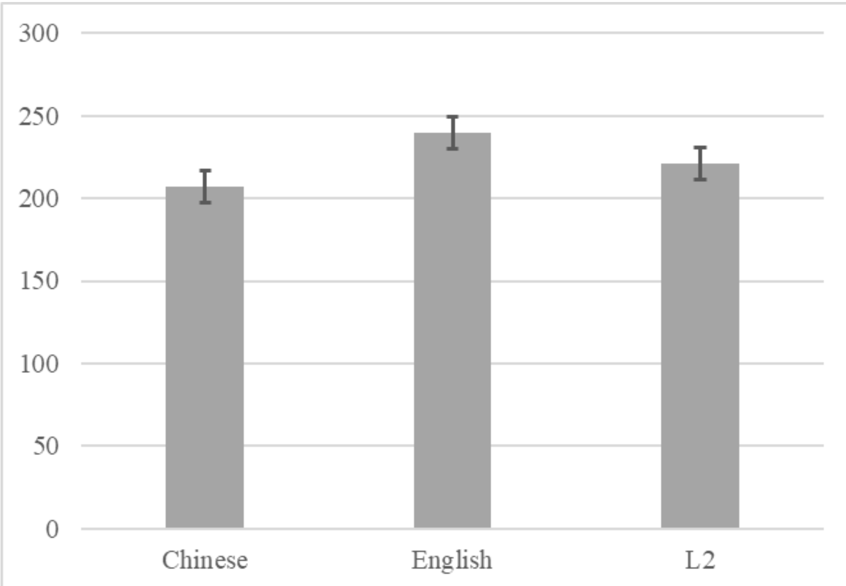
*Means and Standard Deviations of Time (sec.) for Total TVPS-4 and TVPS-4 Sections*

| | Native Chinese (n=5) | | Native English (n=5) | | Chinese L2 (n=5) | |
|---|---|---|---|---|---|---|
| Test | *M* | *SD* | *M* | *SD* | *M* | *SD* |
| TVPS-4 Total | 206.781 | 94.953 | 239.839 | 80.416 | 220.88 | 72.224 |
| Visual Discrimination | 35.844 | 7.079 | 42.679 | 6.748 | 40.775 | 5.916 |
| Visual Memory | 27.205 | 2.853 | 30.233 | 11.457 | 30.698 | 12.264 |
| Spatial Relations | 36.623 | 5.021 | 50.983 | 16.243 | 45.119 | 7.742 |
| Form Constancy | 73.684 | 13.223 | 49.524 | 23.998 | 74.084 | 16.372 |
| Sequential Memory | 21.867 | 1.561 | 36.691 | 7.728 | 32.006 | 11.396 |
| Figure-Ground | 61.611 | 25.719 | 54.055 | 5.449 | 44.825 | 7.637 |
| Visual Closure | 32.658 | 4.794 | 41.610 | 12.628 | 40.726 | 9.924 |

Table 2 shows the means and standard deviations for time for the total TVPS-4 and the seven TVPS-4 sections for each language group. Overall, the Native Chinese group was the fastest and the Native English group was the slowest. To determine whether these differences are statistically significant or not, a one-way ANOVA for the total TVPS-4 was conducted and no significant effect of group on time was found ($F$ (3.55) = 0.28, $p$=.759) (Figure 3).

**Figure 3**

*Average Time (sec.) for Total TVPS-4*

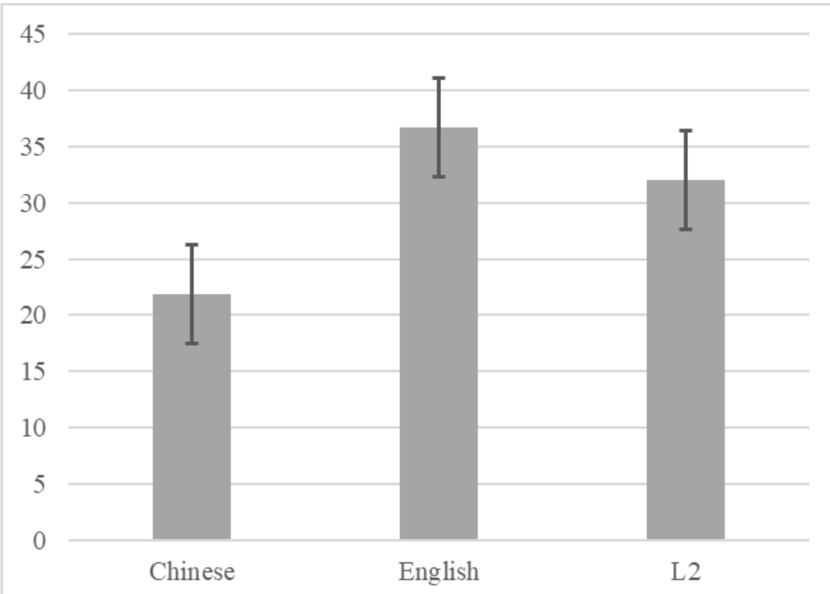



To further test whether these results hold true for each pair, equal variance t-tests were conducted between the groups. The t-test results did not support the hypothesis that the population mean between the groups was different for the total TVPS-4 times (Chinese-English groups $p$=.496; Chinese-L2 groups $p$=.759; English-L2 groups $p$=.651).

One-way ANOVAS for time (Time X Group) for each of the seven sections was conducted, and a significant group effect on time spent was only found for section 5, Sequential Memory, ($F$ (3.88) = 4.49, $p$=.035), as shown in Figure 4. A post-hoc t-test revealed a significant difference between the Native Chinese group and the Native English group, with the Native English group's mean being greater than the Native English groups' mean ($p$=.003). The results did not, however, support the hypothesis that the population means between the native Chinese group and the Chinese L2 group were different ($p$=.084) or that the population means between the native English group and the Chinese L2 group were different ($p$=.469). From this we can infer that the difference between the groups comes largely from Section 5 and that the largest difference is between the native English group and the native Chinese group, with the native English group performing slower than the native Chinese group.

**Figure 4**

*Average Time (sec.) for Section 5, Sequential Memory*




**Word Recall**

A t-test assuming equal variance was performed on the word recall task. We found a significant difference of means between the native Chinese group and the native English group (*p*=.045), with the native Chinese group having a higher average of words remembered, and a significant difference of means between the native English group and the L2 group (*p*=.009), with the L2 group having a higher average of words remembered. There was no significant difference of means between the native Chinese group and the L2 group (*p*=.789).

## Discussion

We assessed a variety of components of visuo-spatial working memory through the TVPS-4 between three different language groups, native English speakers, native Chinese speakers, and Chinese second language learners. We aimed at determining how two different orthographies impact the visuo-spatial portion of working memory and if learning a new orthography alters visuo-spatial working memory. We hypothesized that overall, the native Chinese speakers would perform faster and more accurately than the native English speakers. More specifically, based off Tolchinsky, Levin and colleagues' (2012) study, that the Chinese second language learners would perform faster and more accurately on the visual discrimination portion of the TVPS-4 than the native English speakers, but otherwise would show no noticeable difference from the native English speakers' performance.

**Research Question and Hypotheses**

Our results found that, in answer to the question of how two different orthographies impact the visuo-spatial portion of working memory, orthography has an impact on the sequential memory portion of visuo-spatial working memory. Our study found that the native English group performed less accurately and slower on the sequential memory portion of visuo-spatial memory than the native Chinese group, although no significant differences were found between the native English group and the Chinese L2 group for sequential memory.

This supports the findings of Shu and colleagues (2003) that the process of learning Chinese builds complex, individual visuo-spatial skills and strategies that impact perception, memory, and reasoning and are otherwise not seen to the same extent in alphabetic languages. The sequential memory portion of the TVPS-4 tests the participant's ability to remember forms and sequences and then recognize them when seen again. In the context of Chinese, this can be seen in how speakers must be able to correctly memorize specific layouts of strokes that represent distinct characters and identify them later. This is even more important if the characters are like each other, with the expectation of one or two strokes. English, on the other hand, does not stress this ability.

These findings do not support our second hypothesis that the Chinese second language learners would perform faster and more accurately on the visual discrimination portion of the TVPS-4 than the native English speakers, but instead, we found the difference on the sequential memory portion of the TVPS-4. Our findings on sequential memory contrast with Tolchinsky, Levin, and colleagues' (2012) finding on visual discrimination because we found no significant difference between the three groups' performances on the visual discrimination portion of the TVPS-4. This difference could be because the prior study used Cantonese speaking participants, while the current study used Mandarin-speaking participants, which although both dialects of Chinese, they differ in how speakers learn the language.

Furthermore, the part of the second hypothesis stated that other than the visual discrimination portion, the native English group and the Chinese L2 group would show no discernable difference was not supported. For both time and accuracy, the Chinese L2 group showed a similar pattern to the native Chinese group. For example, on overall accuracy, both groups outperformed the native English group. Further analysis found that there was the Chinese L2 group significantly outperformed the native English group on total accuracy.

This suggests that the impact the Chinese orthography has on visuo-spatial working memory can be found early in the learning process, as the Chinese L2 group had only been studying the language for three months. The timeframe could imply that the impact on visuo-spatial working memory that logograph orthographies have could be in part due to the training and learning process needed to acquire proficiency in that language and orthography, as opposed to a more long-term effect, which supports Zhou and McBride's (2018) finding that pure visual skills had a significant role in non-native Chinese speakers, but not in native Chinese speakers.

Regarding the overall TVPS-4 results, our findings supported our hypothesis that the native Chinese group would perform both faster and more accurately than the native English group on the total TVPS-4. On the total TVPS-4, our study found a significant effect of group on the accuracy, although there was no significant difference between the native English group and the native Chinese group. This lack of significant difference between groups could be because of the limited sample size for each group. There was, however, a significant difference between the total TVPS-4 accuracies of the native English group and the Chinese L2 group.

This finding could be explained by the effect of training and the amount of usage. All the native Chinese group participants reported knowing English for more than ten years and reported using English most of the time. The Chinese L2 group, although they had a lower proficiency in Chinese than the native group, and had practiced Chinese for less time, were being constantly exposed to the language and were actively learning and practicing the language for four days a week. This active learning and practicing could have led the Chinese L2 group to be more attuned to the visual characteristics than the native Chinese group, which aligns with the training effect found in prior studies of Cantonese speakers (McBride-Chang, Zhou, et al., 2011; Tolchinsky, Levin, et al., 2012).

As for time on the total TVPS-4, there was a trend of the native Chinese group performing faster than the native English group, although no significant effect of group on time was found. There was no significant difference found between the groups, which does not support the portion of our first hypothesis about time. Overall, the native Chinese group performed more accurately on the overall TVPS-4 but did not perform significantly faster than the other groups, which partially supports our first hypothesis.

**Visuo-Spatial Working Memory**

Chen and Juola's (1982) orthographic variation hypothesis states that different orthographies activate different word processing mechanisms, which then in turn emphasize varying areas of working memory differently. Our results found that only on sequential memory did the three groups differ significantly. Although this supports the orthographic variation hypothesis by suggesting that a logographic orthography emphasizes the sequential memory portion of visuo-spatial working memory more so than an alphabetic orthography, there is no causal evidence to suggest that alphabetic and logographic orthographies emphasize different portions of visuo-spatial working memory, specifically. Furthermore, the results for the Chinese L2 group did not suggest that learning a new orthography then alters visuo-spatial working memory, meaning we cannot extend the orthographic variation hypothesis to second language learners.

**Chinese and English Orthographies**

Our research also helps to better understand the differences between Chinese and English orthographies and their impact on each other. Prior research has suggested that visual-orthographic skills may be more crucial to learning to read Chinese than to learning to read alphabetic orthographies (Leck, Weekes, & Chen, 1995; Tan, Spinks, et al., 2005; Perfetti, Liu, Fiez, et al., 2007). The current research found that there was a significant difference on the average accuracy for the Total TVPS-4 between the native English group and the Chinese L2 group, with the Chinese L2 group performing more accurately than the English group, which suggests that because visual-orthographic skills are crucial to learning Chinese, that they are the first cognitive skills that will be impacted for beginner second language learners of Chinese.

## Prior Research on Native Chinese Speakers

Our results that, although not significant, the native Chinese group performed on average more accurately than the native English group for the total TVPS-4 supports Chen and Juola's (1982) finding that native Chinese speakers were more attuned to the visual representation of words than native English speakers, suggesting that native Chinese speakers could have greater visuo-spatial abilities in working memory than native English speakers.

More specifically, our findings found a significant difference between the native Chinese group and the native English group's accuracy on the Sequential Memory section, with the native Chinese group performing more accurately than the native English group. This suggests that maybe the greater visuo-spatial working memory abilities in Chinese speakers, as suggested by Chen and Juola (1982), lay in an area that deals with sequential memory.

## Prior Research on Second Language Learners of Chinese

Overall, the current research's findings supported previous research on visual-orthographic sensitivity in Chinese second language learners (Wang, Perfetti, & Liu, 2003), but did not support prior research on pure visual skills and the use of visuo-spatial skills in early character acquisition (Zhou & McBride, 2018; Kim, 2010).

Kim (2010) found that adult Chinese second language learners tend to bypass the visual stage of character acquisition, possibly because their visuo-spatial skills are not skilled enough to comprehend at this stage. The current study's results, however, found that there was a significant difference between the total accuracy of the native English group and the Chinese L2 group, with the Chinese L2 group performing more accurately than the native English group. This does not support Kim's (2010) finding that Chinese second language learners' visuo-spatial abilities are not skilled enough to fully acquire the visually complex characters.

Furthermore, we found no significant differences for time for either total TVPS-4 and the Sequential Memory section, meaning that the Chinese L2 group did not perform significantly slower or faster on tests of visuo-spatial working memory than either the native Chinese group or native English group. This suggests that they were not compensating for their deficient visuo-spatial abilities by taking longer to process the visual cues than the native Chinese group.

Wang, Perfetti, and Liu (2003) found strong evidence for early visual-orthographic sensitivity in the lexical processing of Chinese characters in the participants with an alphabetic background. Their results suggest that beginning Chinese learners who are already skilled in the alphabetic system demonstrate early visual-orthographic sensitivity in the lexical processing of Chinese characters, and early sensitivity to the structural complexity and compositional relationship of the characters (Wang, Perfetti, & Liu, 2003).

Our results that there was a significant difference between the total accuracy of the native English group and the Chinese L2 group, with the Chinese L2 group performing more accurately than the native English group. This supports Wang, Perfetti, and Liu's (2013) evidence that beginning Chinese learners who are proficient in an alphabetic orthography demonstrate early sensitivity to visual information since our Chinese L2 group did perform more accurately than the English group on the TVPS-4.

Zhou and McBride (2018) found that Chinese second language learners and native Chinese speakers performed comparatively on tests of pure visual skills, which our results did not support. We found that for both accuracy and time on the total TVPS-4, the Chinese L2 group and the native Chinese group had no significant differences in their performances.

**Gardner's Test of Visual Perceptual Skills**

Tolchinsky, Levin and colleagues' (2012) study found that the Cantonese speakers significantly outperformed, on accuracy, Spanish and Hebrew speakers on the visual discrimination portion of the TVPS-4. They attributed this finding to the training effect that character learning has on the development of visual skills of Cantonese speakers (Tolchinksy, Levin, et al., 2012).

Our results, however, do not support Tolchinsky, Levin and colleagues' (2012) findings because we found no significant differences for the visual discrimination portion of the TVPS-4, but we did find significant differences for the sequential memory portion of the TVPS-4. Despite the different results, we can still apply the training effect to help explain our results because, unlike Tolchinsky, Levin, and colleagues' (2012) research, our study tested all the areas of visuo-spatial working memory on the TVPS-4. The training effect can help explain any differences on visuo-spatial working memory between two orthographies, although it does not help explain why certain sub-areas of visuo-spatial working memory are different between orthographies, such as we found in our study.

**Word Recall Task**

The findings of the word recall task suggest that the visuo-spatial load that the Chinese orthography places on the speaker lends itself to increased storage capabilities of working memory, potentially because there is more information to remember for each character, which is not shared with other characters. In an alphabetic orthography, however, the speaker only needs to remember a distinct number of individual letters at a time, although the configurations can change. Another interesting finding from the word recall task is that in comparison to both the native Chinese group and the L2 group, the native English group had a significantly less average of words remembered. Since there was no significant difference between the native Chinese group and the L2 group, this suggests that even three months of learning a logographic orthography can impact the storage abilities of working memory.

**Implications**

The current study's findings could help promote more targeted language teaching practices by helping language instructors understand how certain languages impact visuo-spatial working memory. Because our results did find a difference between native English and native Chinese participants and their visuo-spatial working memory, specifically sequential memory, teachers can address teaching native English speakers Chinese as a second language. Specifically, language teachers can create lesson plans that emphasize teaching the visual aspect of Chinese characters to help support English speakers reduced visuo-spatial working memory, as compared to native Chinese speakers and to help facilitate their improvements in visuo-spatial working memory. For example, starting students off learning basic visual characters, accompanied by an emphasis on the phonological aspect, since prior research has found that alphabetic speakers tend to rely more on phonological cues (Wang, Koda, et al., 2003; Smythe et al., 2003; Cole & Pickering, 2010).

The current study provides an addition to current research in visuo-spatial working memory and orthography because it was one of the first to examine seven different areas of visuo-spatial working memory, instead of visuo-spatial working memory as a whole. Since not much current research studies the impact orthography has on these individual areas of visuo-spatial working memory, the current study will offer new ideas for continuing research in this field and provide a sound basis for the justification of future research in this field.

**Limitations and Future Directions**

The current research was limited in the population sizes for each group, as we only surveyed 5 participants for each of our three groups. Because of the small sample size, we cannot rule out that the differences may be impacted by individual differences not attributed to language or orthography. Furthermore, the current research was limited to one Chinese second language learning class, which was the beginner level. Future research might analyze multiple levels of second language learners to better understand if proficiency is a necessary factor in determining the extent to which orthography impacts visuo-spatial working memory.

Other possible future research could look to extend the current research to encompass a larger population for each group to see if the differences that were found remain. Furthermore, future research could look to include, in addition to the logographic and the alphabetic orthographies, the third type of orthography, syllabic, to see if the current differences extend beyond the relationship between the logographic orthography and the alphabetic orthography.

References

Baddeley, A. D. (2003). Working memory and language: An overview. *Journal of Communication Disorders, 36,* 189-208.

Baddeley, A.D. (2002). Is Working Memory Still Working?. *European Psychologist, 7*(2), 85-97.

Biederman, I., & Tsao, Y.C. (1979). On processing Chinese ideographs and English words: Some implications from Stroop-test results. *Cognitive Psychology*, *11*, 125-132.

Bugaiski, P. (2017). *Testing and Interpretation of Visual Perceptual Skills* [PowerPoint slides]. Retrieved from https://www.aoa.org/Documents/CO/Testing%20and%20Interpretation%20of%20Visual%20Perceptual%20Skills%20-%20CVS%202017.pdf.

Chen, H.C., & Juola, J.F. (1982). Dimensions of lexical coding in Chinese and English. *Memory and Cognition*, *10,* 216-224.

Cole, R., & Pickering, S. J. (2010). Phonological and visual similarity effects in Chinese and English language users: Implications for the use of cognitive resources in short-term memory. *Bilingualism: Language and Cognition, 13*(4), 499-512.

Corcos, E.M., Kruk, R.S., & Willows, D.M. (1993). *Visual processes in reading and reading disabilities.* Makwah, NJ: Erlbaum Associates.

Daniels, P.T., & Bright, W. (1996). *The world's writing systems.* Oxford, UK: Oxford University Press.

Dehaene, S. (2009). *Reading in the brain*. London: Viking.

Kim, S.A. (2010). *Developmental stages in reading Chinese as a second language* (Doctoral dissertation). University of Illinois Urbana-Champaign, Champaign, USA.

Leck, K.J., Weekes, B.S., & Chen, M.J. (1995). Visual and phonological pathways to the lexicon: Evidence from Chinese readers. *Memory and Cognition, 23*, 468-476.

Liu, D., Chen, X., & Chung, K. K. H. (2015). Performance in a visual search task uniquely predicts reading abilities in third-grade Hong Kong Chinese children. *Scientific Studies of Reading, 19*, 307-324.

Liu, D., Chen, X., & Wang, Y. (2016). The impact of visual-spatial attention on reading and spelling in Chinese children. *Read Writ, 29,* 1435-1447.

McBride-Chang, C., Cho, J.R., Liu, H., Wagner, R.K., Shu, H., Zhou, A., et al. (2005). Changing models across cultures: Associations of phonological awareness and morphological structure awareness with vocabulary and word recognition in second graders from Beijing, Hong Kong, Korea, and the United States. *Journal of Experimental Child Psychology, 92*(2), 140-160.

McBride-Chang, C., Chow, B.W.Y., Zhong, Y.P., Burgess, S., & Hayward, W.G. (2005). Chinese character acquisition and visual skills in two Chinese scripts. *Reading and Writing: An Interdisciplinary Journal, 18*, 99-128.

McBride-Chang, C., Zhou, Y., Cho, J.R., Aram, D., Levin, I., & Tolchinsky, L. (2011). Visual spatial skill: A consequence of learning to read?. *Journal of Experimental Child Psychology, 109*, 256-262.

Muljani, D., Koda, K., & Moates, D.R. (1998). The development of word recognition in a second language. *Applied Psycholinguistics*, *19*(1), 99-113.

Perfetti, C.A. (1999). Comprehending written language: A blueprint of the reader. In C. Brown & P. Hagoot (Eds.), *The neurocognition of language* (pp.167-208). New York: Oxford University Press.

Perfetti, C.A., Liu, Y., Fiez, J., Nelson, J., Bolger, D.J., & Tan, L.H. (2007). Reading in two writing systems: Accommodation and assimilation of the brain's reading network. *Bilingualism: Language and Cognition, 10*(2), 131-146.

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

Smythe, I., Everatt, J., Gyarmathy, E., Ho, C.S.H., & Groeger, J.A. (2003). Short-term memory and literacy: A cross language comparison. *Educational and Child Psychology, 20*(3), 37-50.

*Test of Visual Perceptual Skills-4.* (2017). Novato, CA: Academic Therapy Publications.

Tolchinksy, L., Levin, I., Aram, D., & McBride-Chang, C. (2012). Building literacy in alphabetic, abjad and morphosyllabic systems. *Read Writ, 25*, 1573-1598.

Vellutino, F. R., Tunmer, W. E., Jaccard, J. J., & Chen, R. (2007). Components of reading ability: Multivariate evidence for a convergent skills model of reading development. *Scientific Studies of Reading, 11*(1), 3-32.

Wang, M., Koda, K., & Perfetti, C.A. (2003). Alphabetic and nonalphabetic L1 effects in English word identification: A comparison of Korean and Chinese English learners. *Cognition, 87*(2), 129-149

Wang, M., Perfetti, C.A., & Liu, Y. (2003). Alphabetic readers quickly acquire orthographic structure in learning to read Chinese. *Scientific Studies of Reading, 7*(2), 183-208.

Zhou, Y., & McBride, C. (2018). The same or different: An investigation of cognitive and metalinguistic correlates of Chinese word reading for native and non-native Chinese speaking children. *Bilingualism: Language and Cognition, 21*(4), 765-781.

**Appendix A**

**Language Background Survey**

1. Age: ❑ 17 ❑ 18 ❑ 19 ❑ 20 ❑ 21 ❑ 22 ❑ 23

2. Gender: ❑ Male ❑ Female ❑ Prefer not to say ❑ Other: ___________

3. How many languages do you know? ❑ 1 ❑ 2 ❑ 3 ❑ 4 ❑ 5 ❑ 6 ❑ 7 ❑ 8+

Individual Language Portion: Depending on the answer to question 3, participants were shown the respective amount of language specific questions. For example, if they indicated they knew two languages, they would be shown this question twice, once for each language.

4. For your first language provide: When you began learning the language, how many years you have studied/used it, in what setting you learned the language (natural AKA without classroom study, or classroom), and how much you use that language. For example: English; native speaker; natural; 100% ______________________________________

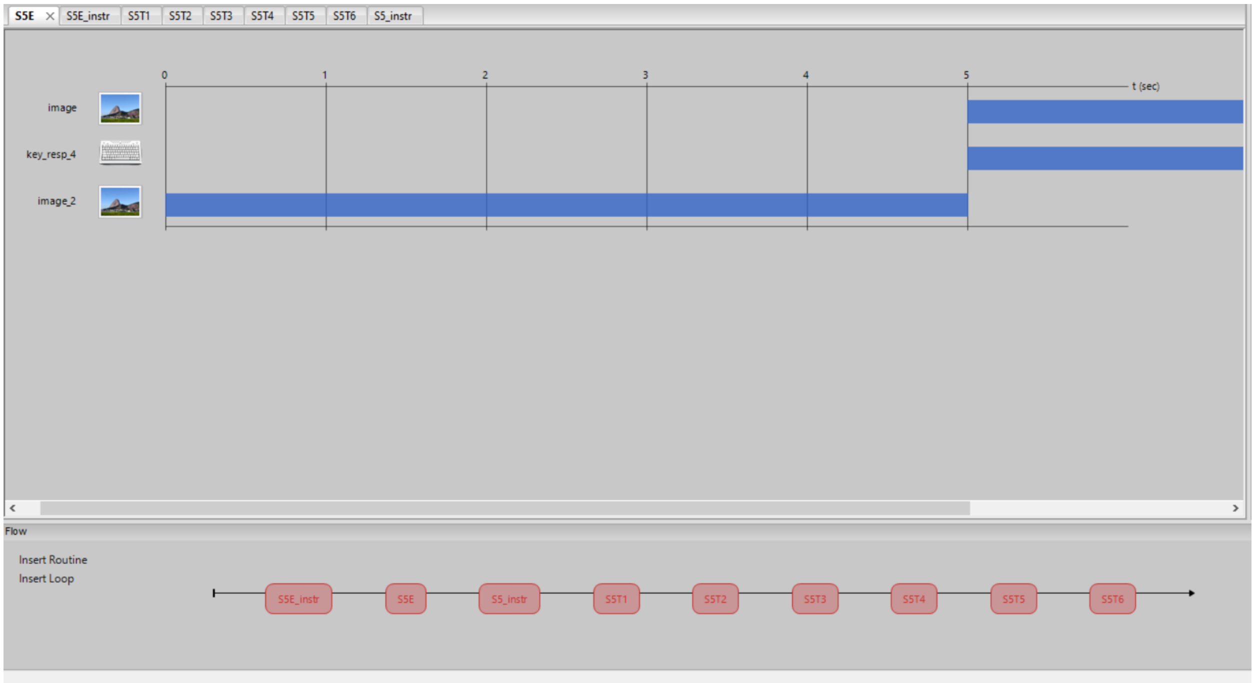
Emory Language Class Portion

5. In the case that you are learning a language at Emory University, please provide what language and level class you are in: ____________________________________

6. If you are currently taking Chinese at Emory, please provide the name of your professor: ____________________

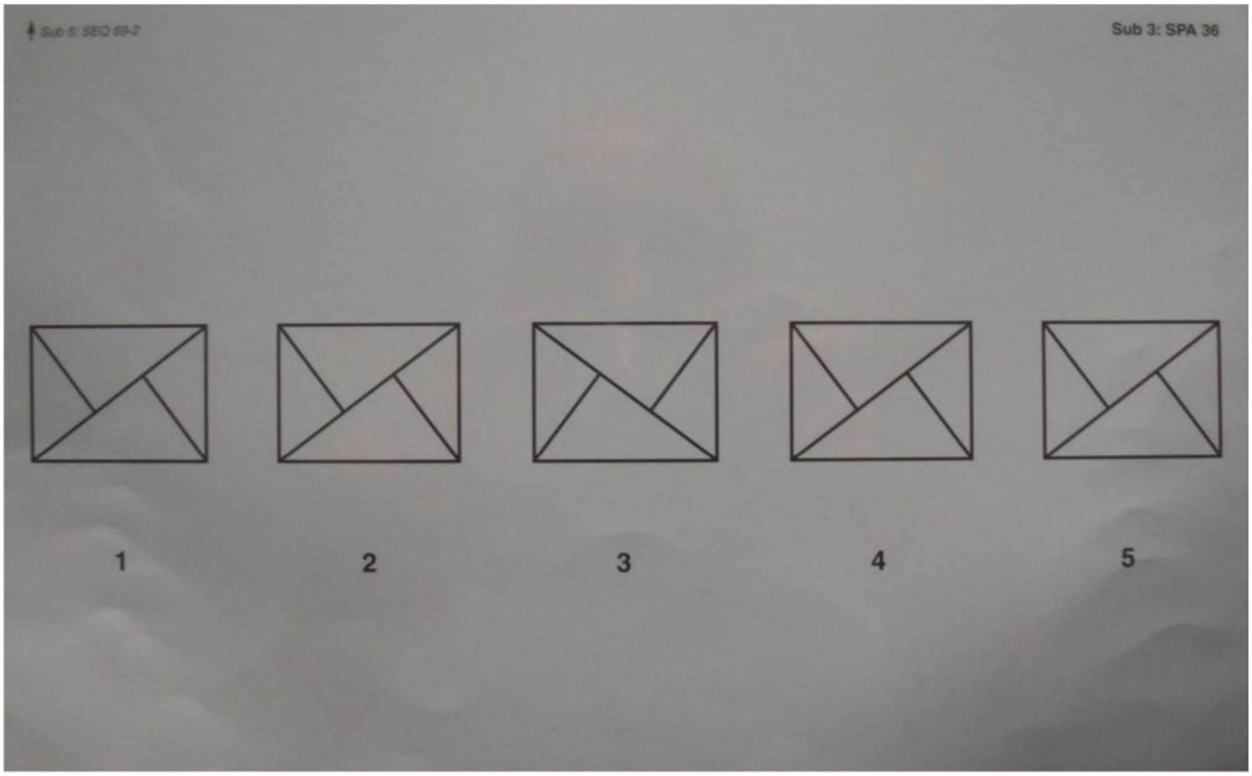
# Appendix B

## Screenshot of Psychopy Flow for Section 5



## Appendix C

### Original TVPS-4 Section 3 Example Item




### Computer Adapted TVPS Section 3 Example Item