LANGUAGE AND WORKING MEMORY CAPACITY IN EARLY ADULTHOOD: CONTRIBUTIONS FROM FIRST AND SECOND LANGUAGE PROFICIENCY

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(ABSTRACT)

The aim of this project was to investigate the impact of language proficiency (represented in first and second language) on working memory capacity. A sample of 100 college students from Virginia Tech University completed an on-line survey, performed 2 computer-based working memory capacity tasks (the OSPAN and the Letter Rotation) and had their first language (L1) as well as their second language (L2) proficiency tested. All participants were classified on a five-point likert scale from “poor” to “excellent”. Verbal WMC (as measured by OSPAN) was associated with L2 proficiency. However, the L2 “excellent” group did not differ in their OSPAN from the remaining four groups of L2 proficiency classification. No correlation was found between the two WMC tasks.

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Working Memory (WM) is considered one of the essential constructs within the area of cognitive research. There is general agreement that memory has multiple components, each serving different time and/or processing functions. WM more specifically has gained considerable interest in numerous fields of psychology (including, but not limited to, cognitive psychology, developmental psychology, and neuropsychology) throughout the last two decades. Research in those areas has investigated a variety of topics, such as the relation between WM and general intelligence (e.g. Conway, Kane, & Engle, 2003), its structure from early childhood to adolescence (e.g. Gathercole, Pickering, Ambridge, & Wearing, 2004), and its close connection to other constructs like temperament and language (e.g. Adams & Gathercole, 2000; Wolfe & Bell, 2004). The purpose of this study was to explore the impact of first language (L1) and second language (L2) proficiency on working memory capacity in a college-age group of students.

A Dual-Store System

Brief information on the evolution of memory as a dual-store system is essential for understanding the construct of WM. Williams James (1918) was the first to introduce the concept of two or more systems of memory. He differentiated memory into primary and secondary systems. The former (primary memory) was considered a short-lived awareness of the specious present and the latter (secondary memory) was considered knowledge of a former state of mind. A neural mechanism was even later proposed for this binary system by Hebb (1949). Later, the idea of a dual store system of memory stimulated further research. The first attempt was initiated by Waugh and Norman (1965). According to their “short-term” model, there exist two stores, namely primary and secondary memory. Primary memory was limited in capacity and held “conscious” information (that information of which people are aware), while secondary memory had unlimited capacity and held “unconscious” information (that of which people were not aware). Waugh and Norman (1965) emphasized that information was retained in primary memory by the use of the process of rehearsal before being passed on to secondary memory.

A few years later, Atkinson and Shiffrin (1968) proposed their two-stage or *modal* model (see Figure 1) that rapidly generated a body of research on human memory. According to their model, there are a number of structurally separate components through which information is transferred. A subset of the information in the sensory registers is chosen for later processing via selective attention and is transferred into a Short-Term Memory (STM) (encoding). The information in the STM is considered *fragile* and decays quickly, so rehearsal is essential to keep it within the STM (maintenance) and to transfer it to a more durable Long-Term Memory (LTM). The information in the STM is assumed to be accessible relatively quickly and effortlessly (retrieval), but there may be a slight slowdown of retrieval speed as a function of the number of items within the STM (Sternberg, 1966). Once lost from the STM, information cannot be retrieved unless it is encoded in the LTM. Retrieval from the LTM, however, is generally considered a slower and more effortful process than that from the STM.

Although it might seem that both models (Waugh & Norman, 1965 vs. Atkinson & Shiffrin, 1968) vary in their theoretical complexity, one central tenet underlying both models was the notion that information was kept in a short-term (or primary) buffer through rehearsal and subsequently transferred to LTM. Evidence in support of this tenet had come from studies on free recall in which participants were presented with a list of words and then asked to recall them in whichever order (e.g. Rundus, 1971). The results from these studies emphasized that when individuals attempted to recall the list immediately, the very first items and the last items in the presented list were usually best recalled. A number of theorists (e.g. Glanzer & Cunitz, 1966; Waugh, 1970) argued that these findings are supportive of two important concepts in human learning, namely “primacy effect” and “recency effect.” The former has to do with the individual’s tendency to quickly recall the first items in a list, a feat that might be interpreted in light of receiving increased rehearsal, while the latter has to do with quickly recalling the last items, a feat that might be interpreted in light of the fact that items were still in the individual’s short-term store at the moment of recall (Ormrod, 1999).

Nevertheless, the notion of transfer of information between short-term and long-term memory stores was later drawn into question. Bekerian and Baddeley (1980) conducted a classic study which examined how new information was remembered. Although individuals in this study were exposed to 1000 exposures about a new frequency of the BBC radio broadcast via radio, television, newspaper, and direct mailings (an average of 25 presentations per day) over many weeks, surprisingly little learning (i.e. little evidence of memory) occurred. This suggests that the notion that transfer from short-to long-term store is simply a matter of repeating information often enough until it is simply “put into” the store, is false. In other words, such studies have placed serious theoretical limitations on dual-store concepts of memory which claimed that long-term learning of material essentially resulted from its rehearsal in the short-term store.

In view of conflicting results obtained in free-recall studies, the concept of “the levels of processing” was proposed by Craik and Lockhart (1972). This model was viewed as an alternative to theories of memory that postulated separate stages for sensory, short-term and long-term memory. According to the levels of processing framework, stimulus information is processed at multiple levels simultaneously depending upon its characteristics. Furthermore, the "deeper" the processing, the more the information will be remembered. For example, information that involves strong visual images or many associations with existing knowledge will be processed at a deeper level than information that involves less or no encoding (Craik & Lockhart, 1972).

Similarly, information that is being attended to receives more processing than other stimuli/events. The levels of processing framework, also, supports the finding that we remember things that are meaningful to us because this requires more processing than meaningless stimuli. This, in turn, has since then promoted most researchers to view memory as being composed not only of static storage components but also of *active* cognitive processes. Consequently, many psychologists (e.g. Cowan, 1995) have conceived WM as being a more complex construct than STM. Others have considered STM as a subset of WM based on the notion that WM includes both the storage as well as the processing of different mental activities like learning, reasoning and comprehending (Haberlandt, 1999).

Working Memory

More than three decades ago, Baddeley and Hitch (1974) proposed that the concept of a *unitary* STM system should be replaced by a *multicomponent* WM model, which they defined as the mechanism underlying the control, regulation, and active maintenance of task-relevant information while performing a cognitive task (Baddeley & Hitch, 1974). Therefore, WM involves both simultaneous storage as well as processing of information (Richardson, 1996). Such a system is crucial for everyday cognitive tasks, like reading a newspaper article or doing mental arithmetic problem, and has been proclaimed the most significant achievement of the evolution of human mind (Goldman-Rakic, 1992; Smith, Jonides, & Koeppe, 1996).

Researchers in many disciplines (e.g. cognitive psychology, neuroscience, and psycholinguistics) have expressed general agreement with the concept of WM as described above. However, by examining the literature one could notice some variability in the views regarding the specific cognitive architecture of WM as a construct. To illustrate, one group of researchers views WM as a single executive system which regulates storage as well as processing functions (e.g. Engle, Cantor, & Carullo, 1992). Another group still perceives WM as a unitary construct, but tends to limit its functions (i.e., its storage and its processing) to either language-specific tasks such as language comprehension (e.g. Just & Carpenter, 1992) or more complex tasks including not only the language component but other cognitive processes as well such as arithmetic operations (e.g., Conway & Engle, 1996). A third group of researchers that is led by Baddeley and Hitch rejects categorically a unitary construct governed solely by central executive function and proposes in its place a multicomponent construct in which subsystems provide either storage or processing functions, or both, for such cognitive tasks as learning, reasoning, and language comprehension (e.g., Baddeley, 1986; Baddeley & Hitch, 1974; Gathercole & Martin, 1996).

Indeed, unitary approaches generally regard WM as a single executive system responsible for both storage and processing functions and concentrate on the extent to which certain cognitive tasks like reasoning, comprehension and individuals' overall working memory capacity (WMC) correlate. The correlations generated between cognitive tasks and WMC allow for, in turn, a theoretically-based model which is used to provide predictions for individual differences in relevant cognitive tasks (Baddeley, 1992). For the most part, experiments carried out from a unitary approach have reported an association between WMC and speech production (Daneman, 1991; Daneman & Green, 1986), listening comprehension, reading comprehension (Daneman &

Carpenter, 1980; Daneman & Merikle, 1996), as well as comprehension of syntactically complex sentences by adults (Carpenter, Miyake, & Just, 1994; King & Just, 1991).

Working Memory Models

The construct WM has become so popular that numerous researchers have attempted to develop different models that reflect their point of interest. Shah and Miyake (1999) have pointed out, however, that four of these models are closely related to one another: Baddeley's multicomponent model, Engle's controlled attention model, Cowan's embedded-processes model, and Lovett's Adaptive Control of Thought - Rational (ACT-R) model. These four models stress a close relationship between *attention* and WM. The first two models (those of Baddeley and Engle) will be discussed in detail in the coming section. Cowan's model (1988) was originally developed to synthesize a vast array of findings on attention and memory. Although it might not be perceived as a model per se, its main essence is that mnemonic functions (which preserve information that can be used to do necessary work) collectively make up WM. On the other hand, Lovett's model (1999) deals with the amount of information the individual could simultaneously attend to by limiting the total amount of "source activation" (Lovett, Daily, & Reder, 2000; Lovett, Reder, & Lebiere, 1999).

Baddeley's Multicomponent Model

Baddeley and Hitch (1974) became interested in STM and they reached the conclusion that all models of STM had two things in common that could be put to use. First, all models assumed that STM had limited storage and processing capacity and, second, that verbal memory span depended on STM. So if individuals were asked to remember a list of digits, those digits would subsequently occupy the limited space. Now if the individuals were asked to carry out reasoning or comprehension tasks at the same time, it would be very difficult for them. This notion of dual tasks was supposed to exercise the WM of the individuals. To the surprise of Baddeley and Hitch, people were able to remember a list of six digits and carry out comprehension tasks simultaneously.

Based on their findings, Baddeley & Hitch (1974) proposed their multi-component model of WM (see Figure 2). It consisted of three major components: the first is a phonological loop (PL) specialized for verbal material; the second is a visuospatial sketchpad (VSSP) specialized for visual and spatial material; and the third is a central executive that regulates the activities of the first two components and utilizes the information stored in them. The sub-components of the PL (Baddeley, 1986) include a phonological store that represents material in a phonological code which decays with time unless the second component (VSSP) and a rehearsal process helps in refreshing the decaying representations. The sub-components of the VSSP (Logie, 1995) are the visual store, in which the physical characteristics of objects and events can be represented, and the spatial mechanism, which is used for planning movements and may serve a rehearsal function.

The central executive, according to Baddeley's model (1986) is responsible for attentional controlling of resources and information in the WM system and is also the component most closely linked to the unitary concept of WM (e.g. Just & Carpenter, 1992). Recently, Baddeley (2000) has revised his model by adding a fourth component "the episodic buffer", which encodes, integrates, and retrieves information in the form of conscious awareness (Baddeley, 2000).

Engle's Model of WMC

The second WM model (Engle's) has basically focused on the notion of WMC. To illustrate, Engle and his colleagues believe that WM is a system that is comprised of the following components: a store in the form of LTM traces active above threshold, processes that are necessary for achieving and maintaining this activation, and controlled attention (Barrett, Tugade, & Engle, 2004). Furthermore, they believe that their last component of controlled attention, a term that has been used by Posner and Peterson (1990) and is similar to WMC, is not about memory or storage per se but about controlled attention. Thus, WMC, according to this view, is about the individual’s ability to control attention and avoid or inhibit distractions (Engle & Oransky, 1999)

This view of a controlled-attention of WMC is consistent with Baddeley's (1986, 1993, 1996) proposal that the central-executive component of WM may be analogous to the Supervisory Attentional System (SAS) described by Shallice and colleagues (Norman & Shallice, 1986; Shallice & Burgess, 1993). According to Shallice (1982), SAS is a limited capacity system and is used for a variety of purposes like tasks involving planning or decision-making or in novel situations, etc. In particular, when a *prepotent* action is activated but conflicts with the individual's goal state, the SAS biases the action-selection process by providing additional activation to a more appropriate action schema and by inhibiting the activation of the inappropriate schema. It hence allows attentional control over action by providing a means with which to override interference from powerful environmental stimuli and habitual responses (Shallice, 1982).

Consequently, WMC is a domain independent, limited capacity processing resource that individuals use to keep relevant information active and available, while at the same time filtering out distraction. Results of the studies conducted by Engle and his colleagues have demonstrated that individuals with higher WMC do better on standardized college admission tests, intelligence tests, and reading comprehension tests (e.g. Conway, et al., 2003; Engle, Tuholski, Laughlin, & Conway, 1999).

Methods of assessing WM

As previously pointed out, WM, according to Baddeley's WM original model, is divided into a modular three-component system that is comprised of the central executive in addition to two slave systems, PL and VSSP. In the following section the focus will be on the various methods researchers have tackled to assess WM using both verbal (i.e. the PL) as well as spatial WM (i.e. the VSSP).

Verbal Working Memory

Following the *individual difference* perspective, Daneman and Carpenter (1980) carried out one of the most prominent studies about verbal WM. In this study, the researchers came up with a *reading span memory task* that is targeted to tap individuals' storage and processing functions. In a typical assessment of verbal WM using this task, research participants are asked to read a series of sentences in sets while simultaneously retaining the final words in each sentence. As the test continues, the number of sentences in a set increases and, as a result, the number of sentence-final-words to be retained also increases. Hence, participants are faced with a situation in which incremental demands placed on processing and storage functions would eventually prevent them from recalling all the final words. The point at which this processing and storage saturation occurs is referred to as an individual's "memory span" and serves as an index of WMC (Carpenter & Just, 1989; Daneman & Carpenter, 1980). Daneman and Carpenter (1980) also devised two other variants of the reading span test: the oral reading span, in which research participants read aloud each sentence as it is presented, as well as the listening span test, in which a presenter reads each sentence to the participants.

Daneman and Carpenter (1980) found that performance on the above mentioned span tasks correlated with L1 reading comprehension measures (e.g. the verbal Scholastic Aptitude Test [SAT]; with *r*s ranging from .49 to .59) and with more local comprehension measures (answering factual and pronoun-reference questions about prose passages; with *r*s ranging from .42 to .90). Later, Daneman and Merikle (1996) demonstrated that performance on reading span procedures correlated with reading comprehension (as measured by the Nelson-Denny Reading Test; with $r = .52$) and with overall language comprehension scores (as measured by the Verbal SAT; $r = .41$).

Furthermore, Turner and Engle (1989) have developed a task that assesses individuals' verbal WM, namely the Operation Word Span (known as OSPAN). In this task individuals recall words or letters under varying levels of WM loads. This task has been used extensively to assess individual differences in WM and how these differences relate to a variety of cognitive outcomes (Cantor & Engle, 1993; Conway & Engle, 1994; La Pointe & Engle, 1990; Rosen & Engle, 1997). For example, Rosen and Engle (1997) demonstrated that WMC is important for retrieval of information. The OSPAN procedure will be further discussed in the method section.

VisuoSpatial WM

"Non-verbal" tasks have been developed to assess individuals' spatial WM. These tasks were shown to be related to individuals' general fluid intelligence (*g*) and as predictors of indices of learning ability (e.g. Stanovich, Cunningham, & Freedman, 1984). In fact, a number of studies showed that nonverbal ability is highly correlated with measures of complex memory span related to the central executive (e.g. Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle et al, 1999).

The *n-back task* of visuospatial WM has been widely used in human neuroimaging and psychophysiology studies with older children and adults (e.g. Cohen, Perlstein, Braver, Nystrom, Noll, Jonides, & Smith, 1997). In a typical assessment of WM using the n-back task, participants are presented with a series of items, each appearing one at a time, followed by the next item in the series. The task is to press a button when the item that is being presented at the moment is the same as the one presented a certain number (n) of items earlier.

Indeed, research on spatial WM has investigated various topics on typical and atypical individuals. For instance, a number of researchers have shown that spatial WM is impaired in schizophrenia patients (e.g. Coleman et al., 2002; Keefe et al., 1995; Park & Holzman, 1992). In one study about half of the clinically unaffected first-degree relatives of schizophrenia patients also showed a dysfunction of spatial WM (Park, Holzman, & Goldman-Rakic, 1995).

The relation between spatial WM and other cognitive abilities (e.g. executive functioning) has also been studied. More specifically, Miyake and his colleagues (2001) have investigated how visuospatial WM, executive functioning, and spatial abilities are related. In this study the researchers administered a total of 12 tasks to college students. Two of the tasks were used to assess visuospatial WM; namely the Letter Rotation Task and the Dot Matrix Task. Both tasks require that the participants keep track of a sequence of information while simultaneously remembering its location (or angle). The Letter Rotation Task will be further discussed in the method section.

Neuropsychology of WM

Although Baddeley's model was originally devised for adult STM, it has later been applied to the development of STM in children (e.g., Hitch, Halliday, Dodd, & Littler, 1989). Though the vast majority of research has been done with the help of behavioral experiments on normal participants and brain-injured participants, some amount of research has also focused on the specific brain regions involved in WM with the help of positron emission tomography (PET) and functional magnetic resonance imaging (fMRI). These methods help detect specific regions of individuals' brains that are activated while doing a WM task. More precisely, neuropsychological research on WM has revealed frontal lobe as well as parietal lobe involvement (Jonides et al, 1993; Smith et al, 1995).

From a neuropsychological perspective, two other brain areas have been shown to be specifically intertwined in the process of WM, namely Broca's area and Wernicke's area. The former (Broca's area) is located in the left frontal lobe of the brain. This area has been traditionally considered a language area, with the assumption of an exclusive linguistic involvement. More specifically this area was found to be involved in the phonological loop in studies using PET, as well as in the covert speech tasks using fMRI (e.g. Erhard, et al., 1996; Hinke, Hu, Stillman, Kim, & Ugurbil, 1993). Moreover, Chein and Fiez (2001) investigated the dissociation of verbal WM System components using a delayed serial recall task. Results of this study with young adults indicated that Broca's area showed a pattern of activity during verbal WM.

The second brain area that has been shown to be related to WM is Wernicke's area, which is located in the posterior temporal lobe of the left hemisphere of the brain. In young adults, *event-related haemodynamic responses* (EHRs) peaked significantly in Wernicke's area during the process of phonological decoding during WM tasks (Thierry, Boulanouar, Kherif, Ranjeva, & Demonet, 1999).

Language and WM

As was previously mentioned, within the model of WM according to Baddeley (1986), there exists a crucial language component. More specifically, Baddeley and his colleagues have emphasized the relationship between language and the storage capabilities of the model, particularly phonological memory skills (e.g. Baddeley, Gathercole, & Papagno, 1998).

Developmentally, associations have been identified between children’s receptive language and their phonological memory (Gathercole, Willis, Emslie, & Baddeley, 1992), with better vocabulary knowledge being associated with better phonological memory. Links have also been demonstrated between children’s phonological memory and their expressive language skills (Blake, Austin, Canon, Lisus, & Vaughan, 1994), and it is possible to differentiate the spoken language profiles of young children grouped in terms of their phonological memory skills (Adams & Gathercole, 1995).

To make it even clearer, by definition WM tasks require a processing component and a storage component. For example, the reading span task (Daneman & Carpenter, 1980) requires the reading of sentences (the processing component) while simultaneously the last words of these sentences have to be stored (the storage component). After a number of sentences, the last words have to be reproduced in the order in which they appeared. Variations of the reading span task, often referred to as complex span tasks, have been devised with different processing components such as listening (Siegel & Ryan, 1989), counting (Case, Kurland, & Goldberg, 1982), and arithmetic (Turner & Engle, 1989). The key measure in all these complex tasks is the amount of language information that can be stored while memory processing continues.

Research on the relation between language and WM has been extended to study not only L1 but L2 as well. Harrington and Sawyer (1992), for instance, have investigated the extent to which differences in L2 reading could be reliably related to differences in L2 WMC. In their study, adult Japanese learners of English as L2 were given a series of memory tests both in English and Japanese which included digit and word span tasks as well as a syntactically-simplified version of Daneman and Carpenter's 1980 reading span task. Participants were also tested for reading comprehension using the grammar and reading sections from the TOEFL.

The results showed moderate correlations between measures on reading span and the results from the grammar and reading section of the TOEFL ($r=.54$ to $.57$), indicating that individuals with higher L2 reading span scores did better on the L2 reading tasks. These results were also comparable to correlations obtained with L1 participants in the Daneman and Carpenter's (1980) study.

Other studies (e.g. Osaka & Osaka, 1992; Osaka, Osaka, & Groner, 1993) have studied the relation between WM and L2 learners' reading and global comprehension skills. These studies have also reported results similar to those of Harrington and Sawyer (1992), that reading span measures could predict general L2 language comprehension.

In a recent study, Wolfe and Bell (2004) emphasized the importance of language in children's performance in WM tasks. In that study, receptive language was a predictor of WM performance for children 4 years of age. The researchers conducted three regression equations and language was the only variable amongst the other two (temperament and EEG) to appear in all three equations predicting children's WM performance. In addition, Zaki (2004) demonstrated that language mediated the relation between family SES and cognitive outcome; that is, language was shown to be the key factor in whether children in their preschool years could perform well in tasks that require WM skills.

Language acquisition

Indeed, language acquisition has been the focus of many research studies. Researchers in this field have been divided between two main groups. The first group (the nativists) believes that language is innate while the other group (the empiricists) believes that language is acquired. Noam Chomsky (1957), the father of the nativist theory, believes that individuals are born into this world with a built-in device which enables them to detect certain language categories, such as phonology, syntax, and semantics. He refers to this device as the Language Acquisition Device (LAD). Hence, according to this belief, individuals across the world have the ability to generate universal sentences.

Moreover, adherents of the nativism view of language acquisition perceive the earliest years of childhood as a "critical period", after which the brain loses much of its facility for assimilating new languages. The belief in this notion of a critical period was supported by studies of Lenneberg in the late 1960s when he claimed that children are biologically programmed to acquire language during a fixed period that ends at about the onset of puberty (Lenneberg, 1967).

This notion was further supported by research on the "wild girl". To illustrate, adherents of the critical period notion have taken the case of "Genie" the 13-year-old child who was found strapped to a potty chair in the 1970s as a good example of their hypothesis. Genie, a thirteen-year-old child was found strapped to her potty chair since she was 20 months of age by her abusive father who judged her to be retarded. After removing her from this environment and with all efforts done to teach her basic skills of language in a seven-year period, she had barely learned any language. Though this example seems to be drastic, it has, as well as other similar examples, enhanced the critical period hypothesis (Johnson & Newport, 1989).

Research on L2 acquisition has revealed that the age when individuals first learned second language plays an important role in determining how proficient those individuals will be. Johnson and Newport (1989) have demonstrated in one of the classical studies on L2 acquisition that the earlier the individuals are exposed to a second language, the better their mastery of this language. More specifically, the researchers studied a group of individuals whose L1 was either Chinese or Korean and L2 was English. All the individuals had lived in the United States for 5 years or more. Half of the participants were early learners, having arrived in the U.S. at age 15 or younger; the others were late learners who had immigrated between the ages of 17 and 39. It appeared that the earlier the individuals were exposed to L2, the more proficient they were in L2 acquisition (Johnson & Newport, 1989).

By comparing the performance of young children to adults and how efficiently they can acquire L2, some researchers have stated that at the beginning of their exposure to L2 adults might appear to be more efficient in their acquisition of L2, producing primitive sentences once they are exposed to it. Though it might seem harder for young children to acquire a new language, few years later they may be able to use this language more efficiently and fluently and might even sound like the native speakers of this language. Hence, if a child is exposed to L2 in his/her early childhood period, chances are very likely that this child would learn it at a native level (Johnson & Newport, 1989).

To the researcher's knowledge, few studies have investigated the impact of having two languages on memory. Haritos (2002), for example, demonstrated that bilingual children, from 1st, 3rd, and 5th grade performed better than monolingual children on tasks that require memory strategies. The current study, therefore, was an attempt to explore such an impact. More precisely, the aim of the present study was to examine whether language proficiency, represented in L1 and L2, would influence how early adults' perform on WMC tasks. The model driving this research, which is inspired by Baddeley's original model, is illustrated in Figure 3.

All participants filled out an on-line survey, had their L1 and their L2 assessed, and had their verbal as well as their visuospatial WMC assessed via two computer-based tasks. The following eight research questions were proposed before the beginning of the study:

1) Is L2 proficiency related to Verbal WMC assessed in L1?

2) Is L1 proficiency related to Verbal WMC assessed in L1?

3) Is L2 proficiency related to VSSP WMC assessed in L1?

4) Is L1 proficiency related to VSSP WMC assessed in L1?

5) Is age of L2 acquisition associated with verbal WMC?

6) Is age of L2 acquisition associated with VSSP WMC?

7) Given that the PL (verbal) and VSSP (spatial) are separate components of the WM model, is performance on verbal and spatial WM correlated?

8) Is it possible to predict the WMC performance based on L2 proficiency and age of L2?

Method

Participants

One hundred and five participants were recruited for participation in this study via the Sona Systems- a system for recruiting participants within the psychology department- as well as via sending out a flyer to professors at Virginia Tech (see Appendix A). Sixty nine females and thirty six males with age range between 17 and 22 took part in the study (see Table 1).

Procedures

Experimental sessions took place in the computer lab located in 203 Williams Hall. The computer lab has 20 Dell optiPlex (GX110); all are Intel-Pentium III PCs with two operating systems (Windows XP pro and Windows 2000 pro) installed on each computer. Participants first signed the informed consent form (see Appendix B) and then the computers were used to administer the Verbal WMC and the VSSP WMC tasks as well as a general information survey (see Appendix C). The survey included questions that were used in this study (e.g. age of L2 acquisition) as well as an English verbal test comprised of short answers. Moreover, a number of questions were added to the survey (e.g., gender, GPA) for the purpose of using them in future research. Out of the total 105 participants, 100 participants had valid OSPAN scores and were considered in the data analyses.

Verbal WMC task

Turner and Engle (1989) developed a task called "Operation-Word-Span" (OSPAN) and that was the verbal WM task used in this study. The task was redeveloped by Engle (2003) to be computer-based. Once the program started, each participant was asked to enter his/her assigned number. Then, instructions appeared on the screen informing the participant that his/her task is to memorize letters presented on the screen while solving simple math problems. In the first part of the experiment participants were given practice trials to get familiarized with how the experiment works. This started with practicing the letter part of the experiment. In other words, for the practice set, random letters appeared on the screen one at a time and the participant’s task was to remember each letter in the order presented. After 2-4 letters were shown, 12 possible letters were presented on the screen with a check box beside each letter. The participant’s task was to select each letter in the order presented by mouse clicking on the appropriate check box. The selected letters appeared at the bottom of the screen. Three options appeared on the screen while the participant was selecting the letters (see Figure 4). The first option was “exit” which indicated that the participant was done with his/her selection and that s/he ready to move on to the next trial. If the participant made a mistake s/he could hit the “clear” option to start over. If the participant forgot one of the letters, s/he could click the “space” option to mark the spot for the missing letter. Participants were given some time, as well, to ask the experimenter any questions before starting the letter practice.

Then, after a series of letter practice trials, a screen appeared indicating the start the math practice of the experiment. Hence, a math problem appeared on the screen, e.g. (2*1) +1? (see Figure 5) and the participant’s task was to compute mentally the correct answer (i.e. without the use of a paper and a pencil). A number was then displayed on the next screen, along with a box marked TRUE for the participant to click on if the answer to the math problem was correct and a box marked FALSE for the participant to click on if the answer was not correct. During this part, the computer would compute the mean time it took the participant to solve the math problems and based on that time, the math problem would disappear from the screen if the participant did not respond within certain amount of time (e.g. 3 seconds) and the math problem would be counted as wrong. Then, the participants were given some practice trials with both the letters as well as the math problems before doing the actual task, which required memorizing letters presented on the screen while solving simple math problems.

The number of operation-letter strings in a sequence automatically increased and decreased based on the individual participant’s performance in order to measure the participant's operation span. According to Turner and Engle (1989), operation span measures predict verbal abilities and reading comprehension even though the participants are solving mathematical problems. Engle and his colleagues have argued that this implicates a general pool of resources that is used in every type of verbal WM situation.

The final screen reported the OSPAN score, the total correct letter responses as well as the number of math errors. OSPAN score reports an absolute score, based on the total number correct, but only for perfectly recalled sets. OSPAN score was the variable of interest in this study. The total correct is the number correct in the correct position regardless of whether the trial is perfect or not. If the participant got 12 Math errors, which is equal to less than 85% correct, his/her OSPAN score did not count. This was based on criteria used by Engle and his colleagues (Heitz, R. P., personal communication, May 02, 2005). Descriptive statistics for OSPAN are given in Table 2.

VSSP WMC task

The VSSP WMC task selection was based on the *Letter Rotation Task* of Shah and Miyake (1996; see Figure 6). The original task was completed with paper and pencil and was modified by the experimenter to be a computer-based task procedurally similar to the OSPAN. In this task, the research participant saw a series of capital letters on the computer-monitor at different angles. The participant's task was to identify whether each letter is normal or mirror-imaged while simultaneously keeping track of its angle of orientation. The program started by asking the participant to enter his/her assigned number. This was then followed by a number of practice trials to get the participant familiarized with the task at hand. Moreover, the participant was given a maximum of 3 seconds to respond by mouse clicking to whether the letter shown on the previous screen was normal or mirror-imaged. Hence, a letter was presented on the screen in one of eight possible angles and this letter was shown as either normal or mirror-imaged. In the next screen, the participant had to respond as to whether the letter was shown in the normal mode or the mirror-imaged mode. After a series of letters (one letter was used at a time) have been presented in different orientations (i.e. angles), the participant's task was to report where the top of each letter was pointing to in the order they were presented by clicking on the appropriate box on a grid. The number of letters presented increased from 2 letters to 6 letters.

The program was set up to report in a separate file at the end of the task the total number of correct orientation, the answer to the question of whether the letter was normal or mirror-imaged, as well as the total number of unanswered questions. Following the Myake and Shah (1996) data analysis, the accuracy of the participants in judging whether the letters were normal or mirror imaged was not taken into consideration. Hence, the VSSP WMC scores were based on the total number of correct orientations which is a calculation comparable to the calculation of the OSPAN scores. However, unlike the OSPAN task there was no minimal level of performance necessary for consideration of a valid score (Miyake et al, 2001).

Language Proficiency

L1 Proficiency. As was mentioned earlier, the on-line survey that was completed by all participants contained a verbal English test (see Appendix C). A total number of 20 randomly selected questions from the Scholastic Assessment Test (SAT) were administered to check the participants' L1 proficiency. The first part of the SAT included 10 "sentence completion" questions. Each question contained one or two blanks, and the participant's task was to find the best answer choice to make the sentence make complete sense (Mathur, 2005). The second part of the SAT included 10 "verb definition" questions. Each question contained one verb (e.g., to befog) and 4 choices for the participant to choose from (SAT/M115, 2005).

Each question in the SAT was worth 1 point; for a total of 20 possible points (20= 100%). All scores were then curved because best performance was 90% (M=60.19). Finally, a score out of 5 was used to classify all participants according to their L1 proficiency. The following criterion was used to classify participants' L1 proficiency; participants who got a score of 4.5-5.0

(i.e., 90% or greater) were classified as *excellent* (5.0%), participants who got a score of 4.0-4.4 (i.e., 80% to 89.9%) were classified as *very good* (12.0%), participants who got a score of 3.5-3.9 (i.e., 70% to 79.9%) were classified as *good* (27.0%), participants who got a score of 3.0-3.4 (i.e., 60% to 69.9%) were classified as *fair* (29.0%), and finally participants who got a score of less than 3.0 (i.e., less than 60%) were classified as *poor* (27%). Descriptive statistics for L1 proficiency are given in Table 2.

L2 Proficiency. Finally, at the end of the experimental session, all participants were given a translation sheet (see Appendix D). The translation part was administered to test the reliability of the participants' self-report of their L2 proficiency (see Table 3). The translation sheet consisted of a total of six sentences to be translated to and from the English language. In other words, all participants were given six sentences (3 in the English language and 3 in his/her L2) and the participant's task was to translate the sentences correctly. The sentences consisted of three levels of difficulty and included an "easy" sentence (e.g., *The boy goes to school everyday*), a "question" (e.g., *Which book have you read lately?*), and a "difficult/complex" sentence (e.g., *If I had known that he was coming to the party, I would have made sure to come as well*).

The Cranwell International Center at Virginia Tech provided the researcher with bilingual volunteers to help with the translation scoring and to check the degree of difficulty of the sentences before the start of the project. The following seven languages were included: Chinese, French, German, Japanese, Russian, Spanish, and Arabic (see Table 3 for percentages of participants' identifying with each language). Selection of these languages was based on what the availability of the volunteers that contacted the researcher via the Cranwell International Center.

Two volunteer scorers for each language were used to avoid individual bias in rating. Clear instructions were given to the raters before the rating process. This included the fact that their ratings should not be absolute (meaning, they should not grade based on a perfect translation but rather relative to the set of the papers they were rating) and that each sentence should be rated according to its accuracy on a five-point rating scale from “Excellent” to “Poor”. To make it clearer, the raters were asked to give a grade out of 5 for each of the six sentence translations. The same method of classification used in L1 proficiency was used with L2 proficiency as well.

Then after getting a score for each sentence, the average score was calculated for each participant by adding all scores and dividing by six (the total number of sentences that were translated). Average scores between the two raters were highly correlated (r= .971). Therefore, the two raters’ scores were averaged together to get an L2 proficiency score for each participant and this score was used in the analysis. The final classification of the participants’ L2 proficiency was as follows: *excellent* (20%), *very good* (23%), *good* (20%), *fair* (21%), and *poor* (16%). Descriptive statistics for L2 proficiency are given in Table 2.

Results

Intercorrelations among all continuous variables are shown in Table 4.

1) Is L2 proficiency related to Verbal WMC assessed in L1?

This was analyzed 2 ways: Pearson correlation and ANOVA. Using the Correlational analysis, the answer was yes. As shown in Table 4, the correlation between L2 proficiency (the translation score) and the OSPAN score (Verbal WMC) is .270 (p<.01).

For ANOVA analysis, L2 proficiency group (i.e. 5 groups ranging from excellent to poor) was the grouping variable and the OSPAN score was the dependent variable. Table 5 shows that the *F statistic* from the ANOVA analysis was significant. Table 6 shows group means on the OSPAN score and Table 7 shows that the “poor” group had OSPAN scores that were lower than the fair, good, and very good. However, the excellent L2 group had an OSPAN scores that were not different from the other 4 groups.

2) Is L1 proficiency related to Verbal WMC assessed in L1?

This was analyzed 2 ways: Pearson correlation and ANOVA. Using the Correlational analysis, the answer was no. As shown in Table 4, the correlation between L1 proficiency (the English curved score) and the OSPAN score (Verbal WMC) is .127.

For ANOVA analysis, L1 proficiency group (i.e. 5 groups ranging from excellent to poor) was the grouping variable and the OSPAN score was the dependent variable. Table 8 shows that the *F statistic* from the ANOVA analysis was not significant. Table 9 shows group means on the OSPAN score.

3) Is L2 proficiency related to VSSP WMC assessed in L1?

This was analyzed 2 ways: Pearson correlation and ANOVA. Using the Correlational analysis, the answer was no. As shown in Table 4, the correlation between L2 proficiency (the translation score) and the Letter Orientation score (VSSP WMC) is -.109.

For ANOVA analysis, L2 proficiency group (i.e. 5 groups ranging from excellent to poor) was the grouping variable and the Letter Orientation score was the dependent variable. Table 10 shows that the *F statistic* from the ANOVA analysis was not significant. Table 11 shows group means on the Letter Orientation score.

4) Is L1 proficiency related to VSSP WMC assessed in L1?

This was analyzed 2 ways: Pearson correlation and ANOVA. Using the Correlational analysis, the answer was no. As shown in Table 4, the correlation between L1 proficiency (the English curved score) and the Letter Orientation score (VSSP WMC) is .099.

For ANOVA analysis, L1 proficiency group (i.e. 5 groups ranging from excellent to poor) was the grouping variable and the Letter Orientation score was the dependent variable. Table 12 shows that the *F statistic* from the ANOVA analysis was not significant. Table 13 shows group means on the Letter Orientation score.

5) Is age of L2 acquisition associated with verbal WMC?

This was analyzed using ANOVA; age of L2 acquisition (i.e. three groups) was the grouping variable and the OSPAN score was the dependent variable. Table 14 shows that the *F statistic* from the ANOVA analysis was not significant. Table 15 shows group means on the OSPAN score.

6) Is age of L2 acquisition associated with VSSP WMC?

This was analyzed using ANOVA; age of L2 acquisition (i.e. three groups) was the grouping variable and the Letter Orientation score was the dependent variable. Table 16 shows that the *F statistic* from the ANOVA analysis was not significant. Table 17 shows group means on the Letter Orientation score.

7) Given that the PL (verbal) and VSSP (spatial) are separate components of the WM model, is performance on verbal and spatial WM correlated?

This was analyzed using Pearson correlation. Using the Correlational analysis, the answer was no. As shown in Table 4, the correlation between OSPAN score and the Letter Orientation score is .033.

8) Is it possible to predict the WMC performance based on L2 proficiency and age of L2?

This was analyzed using regression procedures. For the Verbal WMC (OSPAN) regression model, age of L2 acquisition was entered in model 1 and L2 proficiency (actually, L2 translation, a continuous variable) added in model 2. As seen in Table 18, the ANOVA table for regression model 2 was significant. Table 19 shows the regression statistics and demonstrates that L2 proficiency had a significant positive beta, meaning that as L2 proficiency increases (that is, as translation scores increase), so does OSPAN score.

For the VSSP WMC (Letter Orientation) regression model, age of L2 acquisition was entered in model 1 and L2 proficiency (the translation continuous variable) added in model 2. As seen in Table 20, the ANOVA for the regression model was not significant. Table 21 shows the regression statistics and demonstrates no significant betas.

Summary of Results

The only significant finding from this study was that Verbal WMC (as measured by OSPAN) was associated with L2 proficiency. However, the L2 "excellent" group did not differ in their OSPAN from the remaining four groups of L2 proficiency classification.

Post-Hoc Analyses

Several post-hoc analyses were conducted. One question that arose during the planned statistical analyses was whether age of L2 acquisition might have had any impact on how well the participants could do on the L2 proficiency task (i.e., the translation). To examine this point, one-way ANOVA was used to test for a difference among the three "age of L2 acquisition" groups; age of L2 acquisition (less than 6, ages 6-12, more than age 12) was the grouping variable and the L2 translation score was the dependent variable. Table 22 shows that the *F statistic* from the ANOVA analysis was significant. Table 23 shows group means on the

Translation score and Table 24 shows that the “less than 6 years of age” group had translation scores that were higher than the “more than 12 years of age” group.

A second question that arose was whether the non-native English speakers that took part in this study (16%) might have had any impact on the results. However, the same analyses that were conducted in the study were repeated with the native English speakers only and the results did not change.

A third question had to do with whether there might be a relation between the verbal ability of the participants represented in their OSPAN scores and their GPA. To examine this relation, Pearson correlation was used with the total sample size (N=100) and with the native English speakers only (N=84) and the answer was no (*rs* = -.130 and -.198, respectively).

A fourth question was whether re-categorizing the L1 proficiency groups might result in different OSPAN results. In other words, as was noted earlier, very few participants were categorized as being *excellent* in L1 proficiency test (SAT). Hence, the total sample size was re-categorized based on the participants’ total score on the SAT to re-examine whether L1 proficiency might enhance verbal WMC. An examination of the L1 proficiency scores revealed that the sample could easily be divided into quartiles with a similar number of participants in each group. Thus, the following criterion was used: participants who scored 10 points or less were classified as fair, participants who scored 11 or 12 were classified as good, participants who scored 13 or 14 were classified as very good, and participants who scored 15 or more were classified as excellent. To examine this point, ANOVA analysis was used with L1 proficiency group (i.e. 4 groups ranging from excellent to fair) as the grouping variable and the OSPAN score as the dependent variable. Table 25 shows that the *F statistic* from the ANOVA analysis was still not significant. Table 26 shows group means on the OSPAN score.

One final question that was examined was whether the verbal WMC (represented in the OSPAN scores) was related to how well the participants performed on the L2 proficiency task (represented in the translation task). To examine this relation, the participants' OSPAN scores were categorized into 5 levels (from poor to excellent). Hence, ANOVA was used and OSPAN level was the grouping variable and the L2 proficiency was the dependent variable. Table 27 shows that the F statistic from the ANOVA analysis was significant. Table 28 shows group means on the L2 proficiency scores and Table 29 shows that the lowest OSPAN group has the lowest L2 score. However, the mean of the lowest OSPAN group (the poor group) was different only from the "good" OSPAN group but not different from the other 3 groups (*fair, very good*, and *excellent*).

Discussion

General Discussion

The main goal of the present study was to investigate the impact of language proficiency (i.e., L1 and/or L2) on WMC in young adults. In addition, the age of when the participants first learned their L2 was considered and the question of whether this might have any impact on WMC was posed.

Selection of the two WMC tasks was based upon what Baddeley (1986) proclaimed about the two main components of his original model of WM. The first task (the OSPAN task) aimed at assessing the verbal component and the second task (the Letter Rotation) aimed at assessing the visuospatial component. Indeed, two main factors were considered in selecting those tasks. First, both tasks were computer-based tasks and thus easily administered. Second, the two tasks had one thing in common, namely the usage of letters in both of them. This made the two tasks comparable “stimuli-wise”, although the participants had to remember the letters themselves in the OSPAN and had to keep track of their angles of orientation in the Letter Rotation task.

To check the participants’ proficiency in L1 and L2, two tasks were chosen; for L1, a total number of 20 randomly selected questions from two verbal SAT practice websites were administered. As for L2, participants were asked to translate a total number of six sentences from and to the English language. The selection of the translation task was based on the fact that it incorporates a number of basic language skills required to be “proficient” in a second language. In other words, translating sentences properly is a good indication that the individual is able to read the language; that is s/he “comprehends”, and is able to “write” using proper meaning/grammar.

Language proficiency and verbal WMC

As mentioned earlier, SAT-like questions were used to check the participants’ L1 proficiency and to test whether such a level of proficiency might have any impact on Verbal WMC. Indeed, SAT is designed to measure developed verbal and mathematical reasoning ability (Donlon & Angoff, 1985; Messick & Jungeblut, 1981), and is widely used to predict success in college for high school students. So, by looking at the nature of this test and the nature of the OSPAN verbal WMC task, one could suppose a correlation between those two tasks. According to Turner and Engle (1989), OSPAN predicts verbal ability. However, such a correlation was not supported in the present study. In general, the problem might have been in the way L1 proficiency was tested. Looking back at the L1 proficiency scores for the participants in this study, one could conclude that the 20 items were very difficult even though randomly selected from the SAT practice websites. Also, taking selected questions from the test does not necessarily make the L1 instrument a valid measurement. Participants had very low scores

(*M*=61.19%) even after curving their scores. Perhaps this artificially inflated the scores to have more than one participant in the “excellent” L1 group, but this was essential to do the proposed analyses. In hindsight, it might have been more appropriate to use the actual SAT scores before conducting the study.

With regard to L2, one point of interest was to investigate whether participants with high L2 proficiency might be the ones who would score high on Verbal WMC. For that purpose, participants of wide range of exposure to seven different L2 were sought. Each participant was classified as being *poor*, *fair*, *good*, *very good*, or *excellent*. Accordingly, all participants were almost evenly distributed among the five groups because of the directions given to the scorers. As anticipated, the poor group had OSPAN scores that were lower than the *fair*, *good*, and *very good*. Interestingly, however, the excellent L2 group had an OSPAN scores that were not different from the other 4 groups.

However, this “excellent” L2 group mimicked, to a great extent, the sample of this study. In other words, this group had participants who were evenly distributed among the four class levels (i.e. *freshman* to *senior*) hence their average age was not different from the remaining sample. By checking their gender, it was found, still, that they were not different; 60% were female. Moreover, 50% of the participants in this group reported that their L2 was Spanish (a well representative percentage looking at the whole sample).

However, this L2 excellent group had a total of 75% who reported being native English speakers versus 25% who reported being non-native. To check whether such a distribution might have had a detrimental impact on how this L2 excellent group did on the verbal WMC task (OSPAN), scores on this task as well as scores of the L1 proficiency test were examined for the non-native group and compared to the native speakers in the L2 excellent group. By comparing the average score on the OSPAN task, it was found that the non-native speakers actually performed better (*M*=51; range 40-75) if compared to the native English speakers group (*M*=36; range 3-68). So, it was not the case that the non-native speakers lowered the OSPAN scores for this L2 excellent group.

Nevertheless, and as expected, the non-native group did worse than the native group on the L1 proficiency test. Out of the five participants who represent the non-native group, four participants were classified as being “poor” and the fifth participant was classified as “good” on the English proficiency test. On the other hand, 11 out of the 15 participants from the native speakers group were classified as being “good” or better.

Though there might seem that there is no clear explanation as to why the L2 excellent group did not differ with regard to their OSPAN scores from the other L2 groups in the sample of this study, it could however be interesting to conduct a study with a larger L2 excellent sample (including an equal size of native English speakers and non-native English speakers) and examine their verbal WMC.

The dissociation between verbal and spatial WM

The task used in this study to assess the participants’ visuospatial ability (the Letter Rotation task) was not language-based and hence it was not surprising to have no correlation between any of the language proficiency tasks and the VSSP task. Furthermore, results of the present study showed that the two administered WMC tasks (verbal OSPAN and spatial Letter Rotation) were not correlated. Indeed such dissociation between the two WM components is strong and comes from experimental, correlational, neuropsychological, and neuroimaging studies (for reviews, see Baddeley & Logie, 1999; Logie, 1995; Smith & Jonides, 1997). Moreover, this line of research was even extended to include studies on children. Gathercole and her colleagues (1998) demonstrated that performance of 5 and 8 year-old children on verbal and visuospatial serial recall tasks was largely unrelated (Pickering, Gathercole, & Peaker, 1998).

Shah and Miyake (1996) reported one of the most influential and compelling demonstration of the verbal-spatial dissociation in WMC. The researchers' experiment provided preliminary evidence for separate "pools of cognitive resources" for the two working memory components; one for spatial thinking and the other for language processing. Hence, the researchers have argued that a VSSP WMC task (e.g., the Letter Rotation) - not a verbal task- should predict how well individuals could do on "spatial ability" tests. By the same token, a verbal WMC task (e.g. the reading span test) - not a spatial task- should predict how well individuals could do on "verbal ability" tests.

In another study (Friedman & Miyake, 2000) reading span predicted verbal SAT scores more strongly than did a spatial task requiring mental rotation of letters and memory for their orientations (*rs* =.45 and .07, respectively). On the other hand, spatial span predicted a composite of standardized visuospatial tests better than did reading span (*rs* =.66 and .12). In an exploratory factor analysis the spatial span and spatial ability tests yielded one factor, and reading span and verbal SAT yielded another. Similar findings with these same span tasks have been reported by other researchers, with reading span predicting only verbal performance and rotation span predicting only spatial performance (Handley, Capon, Copp, & Harper, 2002).

Age of L2 acquisition

One of the questions addressed in the present study was whether the age when the participants were first exposed to L2 might play any role in how well they perform on the WMC tasks (specially the Verbal OSPAN). However, it turned out that age of L2 was not correlated with any of the WMC tasks. Nevertheless, there was an association between the age of L2 acquisition and L2 translation proficiency, supporting the findings of Johnson and Newport (1989). The participants whose initial exposure to L2 occurred when they were younger than 6 years of age scored much higher on the sentence translations than participants whose initial exposure to L2 occurred when they were older than 12 years of age. This lends support to Lenneberg's (1967) speculation about the implications for L2 acquisition, noting that after the age of 12 (i.e. after puberty) second languages are acquired consciously and with great effort, and often not successfully.

Limitations

The present study had some limitations. For instance, the timing of sessions could have been one factor that affected how well participants did on the WMC tasks. For the most part, sessions with the largest number of participants were administered in the late afternoon. However, these tasks required *controlled attention* and, hence, required that the individual be as alert as possible for a good performance.

Moreover, as mentioned earlier, the items selected for L1 proficiency test (represented in the verbal SAT) seemed to be very difficult, though they were randomly selected, and therefore the group mean turned out to be quite low. Moreover, selecting 20 items only from the SAT seemed to be insufficient to measure the participants' verbal ability. Thus, the L1 proficiency measure used here may not have been representative of the participants' actual verbal ability in L1.

Future Directions

The future directions for research in this area should include a consideration of the abovementioned limitations of the current study. More precisely, in future work, selection of participants could be based on having a sample of equal size number of participants with regard to the amount of exposure to L2.

It might also be more appropriate to focus in future research on just two languages. The present study looked at seven different languages, some of which have similar characters as the English language like the Spanish or the French languages, while others have completely different characters like the Chinese or the Arabic languages. Hence, future research might focus on comparing two languages to see whether having similar characters or not might play a role in enhancing the verbal WMC of the individuals.

Moreover, regarding L1 proficiency, it would be better to check the participants' SAT scores prior to conducting similar studies and have a group of students with high verbal SAT scores as well as high L2 proficiency and another group with lower verbal SAT scores with lower L2 proficiency and see how these two groups differ on verbal WMC tasks like the OSPAN. In addition, as previously mentioned, it would be interesting to compare a two equal size groups (native English speakers and non-native English speakers) and investigate how they could do on verbal WMC tasks.

Finally, future work in this area should thoroughly examine what should be a robust relation between language proficiency and WMC and investigate what specific features of language or working memory ability might be influencing the association between them.

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Table 1: *Demographic Information*

Gender	
Female	65%
Class	
Freshman	21.0%
Sophomore	24.0%
Junior	26.0%
Senior	25.0%
Not reported	4.0%
Native English Speakers	84.0%
Bilinguals	43.0%

N= 100 with valid OSPAN scores.

Table 2: *Summary of Variables of Interest in the Study*

	Min.	Max.	Mean	SD
OSPAN (Verbal WMC)				
Score (75)	.00	75.00	43.50	16.70
Total (75)	4.00	75.00	59.25	13.69
Math Errors	.00	12.00	5.30	2.65
Letter Orientation (VSSP WMC)				
Score (20)	.00	18.00	7.17	5.26
Normal OR Mirror (20)	8.00	20.00	16.30	2.70
Unanswered	.00	8.00	1.42	1.50
L1 Proficiency (SAT)				
Sentence Completion (10)	1.00	8.00	4.96	1.51
Definition (10)	3.00	10.00	7.08	1.74
Total Score (20)	4.00	18.00	12.04	2.72
Percentage	20.00	90.00	60.20	13.61
Percentage Curved	22.22	100.00	66.89	15.12
L1proficiency	1.00	5.00	2.39	1.15
L2 Proficiency (Translation)				
Translation 1 (5)	1.00	5.00	3.64	.89
Translation 2 (5)	1.30	5.00	3.64	.85
Translation Averaged (5)	1.15	5.00	3.64	.86

N= 100 (except for the Letter Rotation Task; N=99)

*Numbers between brackets represent the total possible points.

Table 3: *Summary of L2 Information*

Percentage of L2 participation		
	Chinese	4.0%
	French	15.0%
	German	6.0%
	Japanese	4.0%
	Russian	1.0%
	Spanish	48.0%
	Arabic	22.0%
Age of L2 acquisition		
	Before 6 years of age	29.0%
	Between the ages of 6 and 12	12.0%
	After 12 years of age	59.0%
Where L2 was learned		
	At School	88.0%
	At Home	9.0%
	Abroad	1.0%
	Through interaction (peers, etc.)	2.0%
Self Ratings of L2 reading proficiency		
	Poor	10.0%
	Fair	23.0%
	Good	38.0%
	Very good	19.0%
	Excellent	10.0%
Self Ratings of L2 writing proficiency		
	Poor	17.0%
	Fair	32.0%
	Good	31.0%
	Very good	16.0%
	Excellent	4.0%

N=100

Table 4: *Intercorrelations among Variables of Interest:*

Variable	Oscore	OTotal	OMath	LetterOr.	LetterMir.	LetterUnans.	Eng. Curved	Translation
OScore		.876**	-.172	.033	.313**	-.160	.127	.270**
OTotal			-.115	.045	.285**	-.115	.036	.221*
OMath				-.051	-.144	.014	-.065	.118
LetterOr.					-.017	-.070	.099	-.109
LetterMir.						-.635**	.062	-.022
LetterUnans.							.046	.048
Eng. Curved								.035
Translation								

N= 100

** p<.01

* p<.05

Variables description:

Oscore= OSPAN Score

OTotal= OSPAN Total

OMath = OSPAN Math Errors

LetterOr. = Letter Orientation

LetterMir. = Normal OR Mirror-Imaged

LetterUnans. = Normal OR Mirror (Unanswered)

Eng. Curved = L1 proficiency

Translation = L2 proficiency

Table 5: *ANOVA for the OSPAN Scores and L2 Proficiency*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4340.957	4	1085.24	4.43	.002*
Within Groups	23254.043	95	244.78		
Total	27595.000	99			

**p < .05 one-tailed tests of significance*

Table 6: *Means and Standard Deviations for the OSPAN Scores and L2 Proficiency*

	N	*Mean*	*SD*
Poor	16	30.31	18.80
Fair	21	47.52	14.83
Good	20	46.05	14.07
V. Good	23	49.65	13.68
Excellent	20	40.20	17.26
Total	100		

Table 7: *Multiple Comparisons among the OSPAN Scores and L2 Proficiency*

	(I) *L2 Proficiency*	(J) *L2 Proficiency*	Mean	Sig.
Tukey HSD	Poor	Fair	-17.21*	.011
		Good	-15.74*	.028
		V. Good	-19.34*	.002
		Excellent	-9.89	.333
	Fair	Poor	17.21*	.011
		Good	1.47	.998
		V. Good	-2.13	.991
		Excellent	7.32	.566
	Good	Poor	15.74*	.028
		Fair	-1.47	.998
		V. Good	-3.60	.943
		Excellent	5.85	.761
	V. Good	Poor	19.34*	.002
		Fair	2.13	.991
		Good	3.60	.943
		Excellent	9.45	.286
	Excellent	Poor	9.88	.333
		Fair	-7.32	.566
		Good	-5.85	.761
		V. Good	-9.45	.286

**p* < .05 *one-tailed tests of significance*

Table 8: *ANOVA for the OSPAN Scores and L1 Proficiency*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	351.251	4	87.813	.306	.873
Within Groups	27243.749	95	286.776		
Total	27595.000	99			

Table 9: *Means and Standard Deviations for the OSPAN Scores and L1Proficiency*

	N	*Mean*	*SD*
Poor	27	41.66	15.34
Fair	29	42.96	17.32
Good	27	46.22	18.80
V. Good	12	41.91	17.49
Excellent	5	45.60	6.46
Total	100		

Table 10: *ANOVA for the Letter Orientation Scores and L2 Proficiency*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	95.202	4	23.801	.854	.495
Within Groups	2648.908	95	27.883		
Total	2744.110	99			

Table 11: *Means and Standard Deviations for Letter Orientation Scores and L2 Proficiency*

	N	Mean	SD
Poor	16	7.18	5.47
Fair	21	8.28	6.16
Good	20	8.05	5.37
V Good	23	6.74	5.10
Excellent	20	5.60	4.09
Total	100		

Table 12: *ANOVA for the Letter Orientation Scores and L1 Proficiency*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	79.379	4	19.845	.707	.589
Within Groups	2664.731	95	28.050		
Total	2744.110	99			

Table 13: *Means and Standard Deviations for the Letter Orientation Scores and L1 Proficiency*

	N	Mean	SD
Poor	27	7.07	5.04
Fair	29	6.24	5.50
Good	27	7.40	4.66
V Good	12	9.25	6.38
Excellent	5	6.80	5.89
Total	100		

Table 14: *ANOVA for the Age of L2 Acquisition and the OSPAN Scores*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	463.415	2	231.708	.828	.440
Within Groups	27131.585	97	279.707		
Total	27595.000	99			

Table 15: *Means and Standard Deviations for the Age of L2 Acquisition and the OSPAN Scores*

		N	Mean	SD
OSPAN Scores	Less than 12 years of age	29	44.20	14.86
	Between 6 and 12	12	48.75	16.44
	More than 12	59	42.08	17.60
	Total	100		

Table 16: *ANOVA for the Age of L2 Acquisition and the Letter Orientation Scores*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	34.982	2	17.491	.626	.537
Within Groups	2709.128	97	27.929		
Total	2744.110	99			

Table 17: *Means and Standard Deviations for the Age of L2 Acquisition and the Letter Orientation Scores*

		N	Mean	SD
Letter Rotation Scores	Less than 12 years of age	29	6.51	4.97
	Between 6 and 12	12	6.33	5.19
	More than 12	59	7.66	5.44
	Total	100		

Table 18: *ANOVA for the Regression Equation Predicting OSPAN Scores using Age of L2 Acquisition and L2 Proficiency*

Model		Sum of Squares	df	Mean Square	F	sig.
1	Regression	136.911	1	136.911	.489	.486
	Residual	27458.089	98	280.185		
	Total	27595.000	99			
2	Regression	2072.196	2	1036.098	3.938	.023*
	Residual	25522.804	97	263.122		
	Total	27595.000	99			

**p* < *.05 one-tailed tests of significance*

Table 19: *Results of Regression Analysis Predicting OSPAN Scores Performance*

	β^a	*R*	R^2	*t*	*Sig.*
L2 Age of acquisition	1.002	.070	.005	.497	.620
L2 Proficiency	5.650	.274	.075	2.712	.008

[a] The values in the final equation, with both predictors entered.

Table 20: *ANOVA for the Regression Equation Predicting Letter Orientation Scores, Age of L2 Acquisition and the L2 Proficiency*

Model		Sum of Squares	df	Mean Square	F	sig.
1	Regression	29.043	1	29.043	1.048	.308
	Residual	2715.067	98	27.705		
	Total	2744.110	99			
2	Regression	43.326	2	21.663	.778	.462
	Residual 2	700.784	97	27.843		
	Total	2744.110	99			

Table 21: *Results of Regression Analysis Predicting Letter Orientation Scores Performance*

	β^a	R	R^2	t	*Sig.*
L2 Age of acquisition	.407	.126	.016	.621	.536
L2 Proficiency	-.485			-.716	.476

[a] The values in the final equation, with both predictors entered.

Table 22: *ANOVA for Age of L2 Acquisition and L2 Proficiency*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	13.477	2	6.738	10.811	.000*
Within Groups	60.460	97	.623		
Total	73.937	99			

**p* < .05 one-tailed tests of significance*

Table 23: *Means and Standard Deviations for Age of L2 Acquisition and L2 Proficiency*

	N	*Mean*	*SD*
Less than 6	29	4.1483	.45835
6 to 12	12	3.8708	.86719
More than 12	59	3.3390	.89351
Total	100		

Table 24: *Multiple Comparisons among Age of L2 Acquisition and L2 Proficiency*

	(I) *L2 Proficiency*	(J) *L2 Proficiency*	Mean	Sig.
Tukey HSD	less than 6	6 to 12	.27744	.564
		More than 12	.80929	.000*
	6 to 12	less than 6	-.27744	.564
		More than 12	.53185	.090
	More than 12	less than 6	-.80929	.000*
		6 to 12	-.53185	.090

**p* < .05 one-tailed tests of significance*

Table 25: *ANOVA for the OSPAN Scores and the Re-categorized L1 Proficiency Groups*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	303.368	3	101.123	.356	.785
Within Groups	27291.632	96	284.288		
Total	27595.000	99			

Table 26: *Means and Standard Deviations for the OSPAN Scores and the Re-categorized L1 Proficiency Groups*

	N	*Mean*	*SD*
Fair	27	41.66	15.34
Good	29	42.96	17.32
V. Good	27	46.22	18.80
Excellent	17	43.50	14.95
Total	100		

Table 27: *ANOVA for the L2 Proficiency and OSPAN Groups*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	8.518	4	2.130	3.093	.019*
Within Groups	65.419	95	.689		
Total	73.937	99			

**p < .05 one-tailed tests of significance*

Table 28: *Means and Standard Deviations for L2 Proficiency and OSPAN Groups*

	N	*Mean*	*SD*
Poor	20	3.08	1.18
Fair	18	3.67	.96
Good	24	3.93	.57
V. Good	22	3.70	.68
Excellent	16	3.73	.61
Total	100		

Table 29: *Multiple Comparisons among L2 Proficiency and OSPAN Groups*

	(I) OSPAN	(J) OSPAN	Mean	Sig.
Tukey HSD	Poor	Fair	-.59	.193
		Good	-.85*	.009
		V. Good	-.61	.122
		Excellent	-.64	.146
	Fair	Poor	.59	.193
		Good	-.26	.849
		V. Good	-.02	1.00
		Excellent	-.56	1.00
	Good	Poor	.85*	.009
		Fair	.26	.849
		V. Good	.23	.872
		Excellent	.20	.940
	V. Good	Poor	.61	.122
		Fair	.26	1.00
		Good	-.23	.872
		Excellent	-.03	1.00
	Excellent	Poor	.64	.146
		Fair	.05	1.00
		Good	-.20	.940
		V. Good	-.03	1.00

**p* < .05 one-tailed tests of significance*

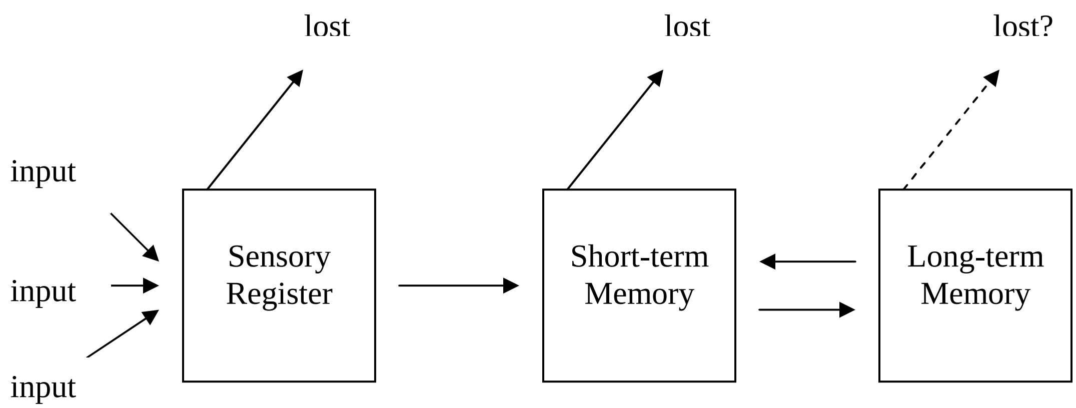


Figure 1
A simplified dual-store model of memory

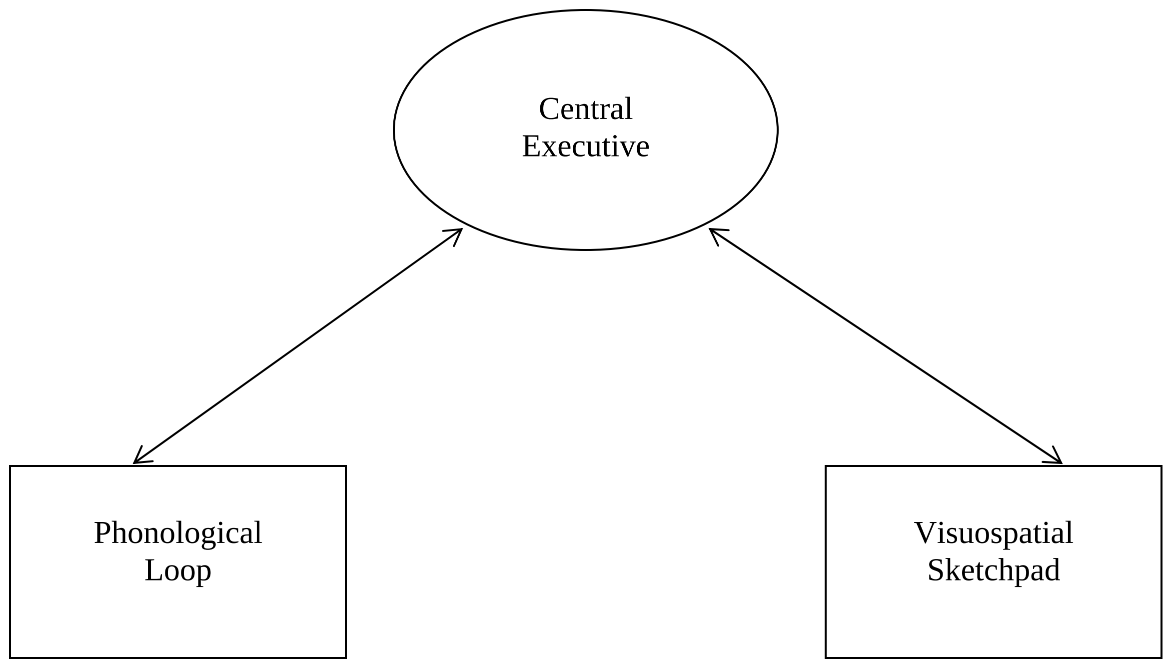


Figure 2
A simplified illustration of the WM model

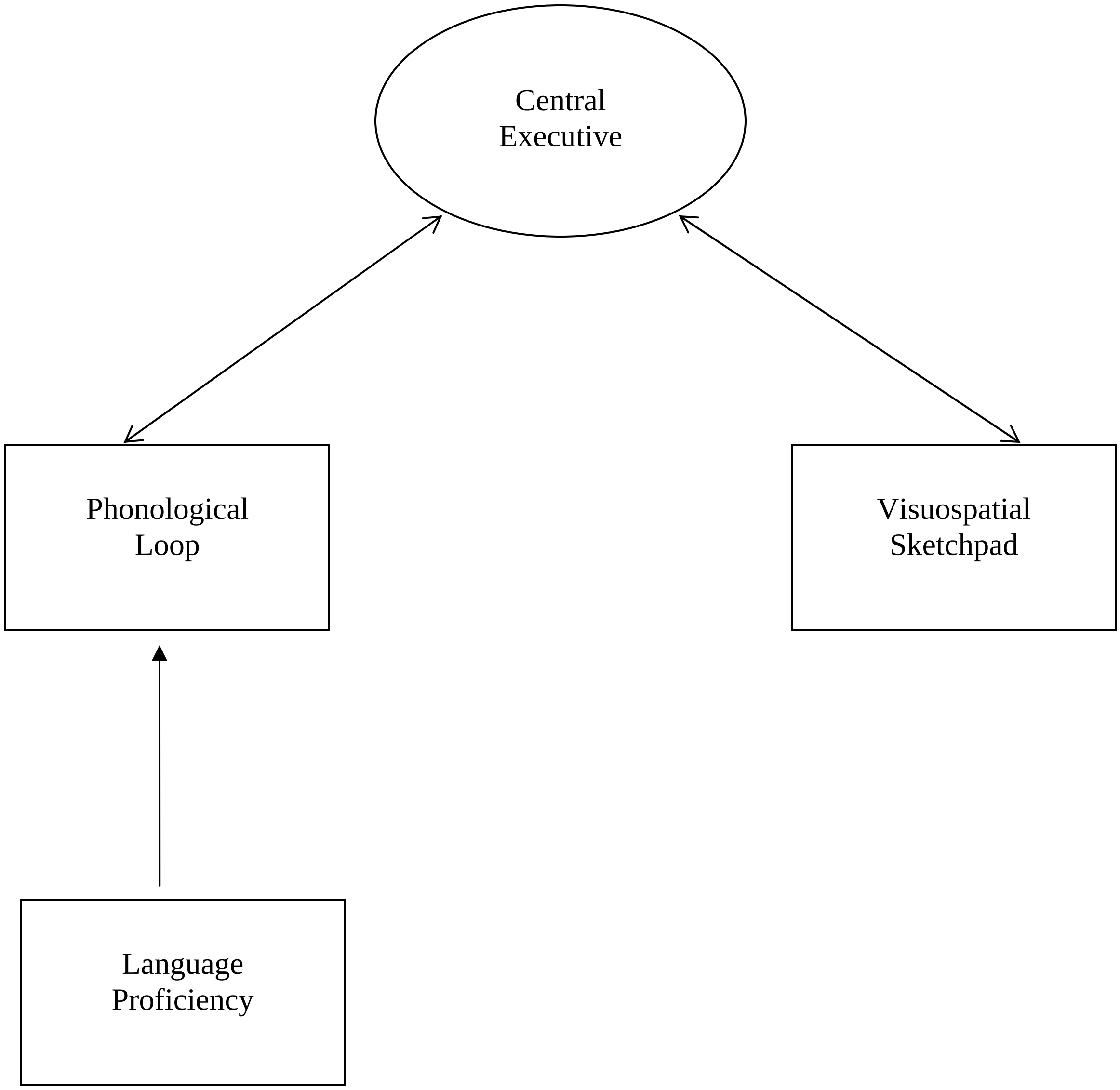


Figure 3
Illustration of the suggested model for the present study

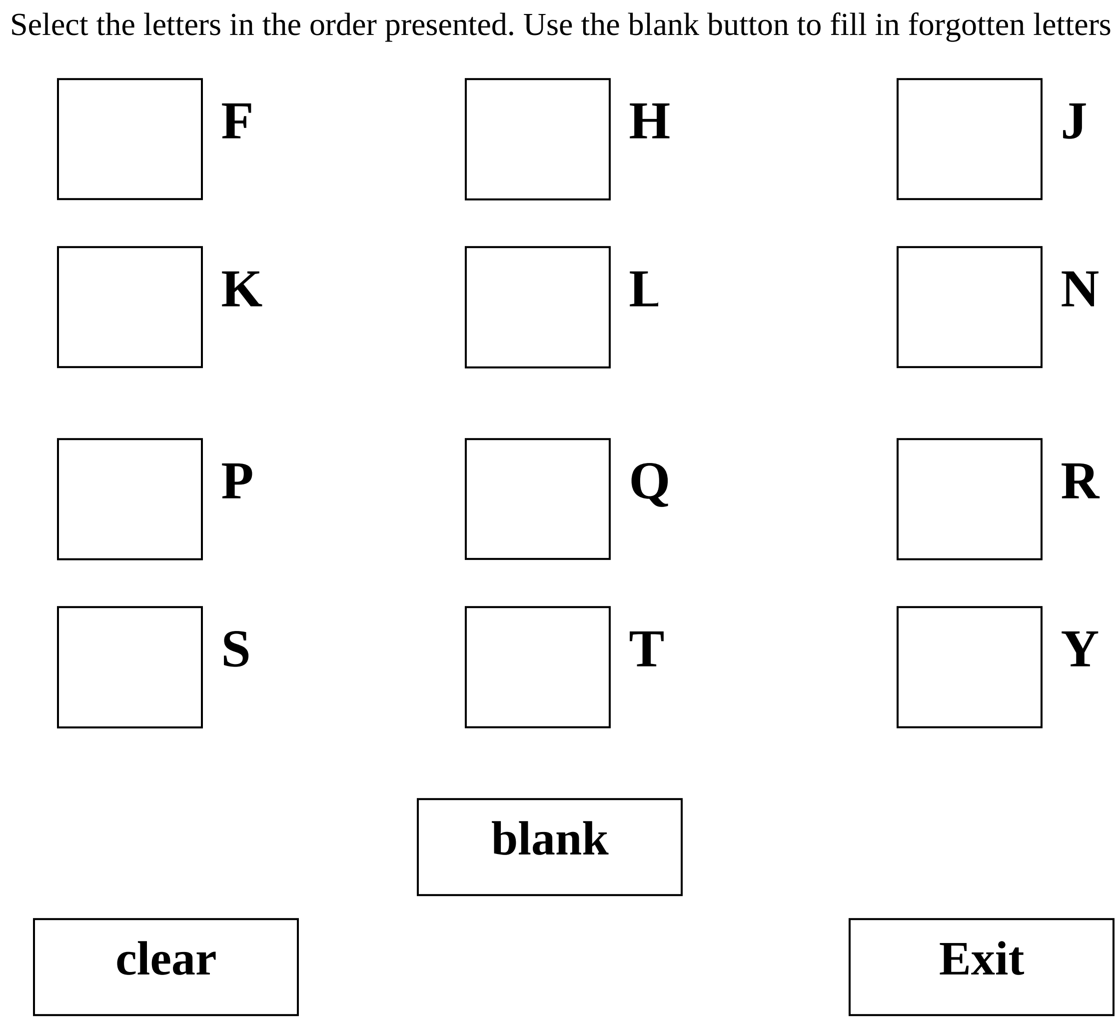


Figure 4
Illustration of the letter practice

(1*2)+1?

When you have solved the math problem, click the mouse to continue

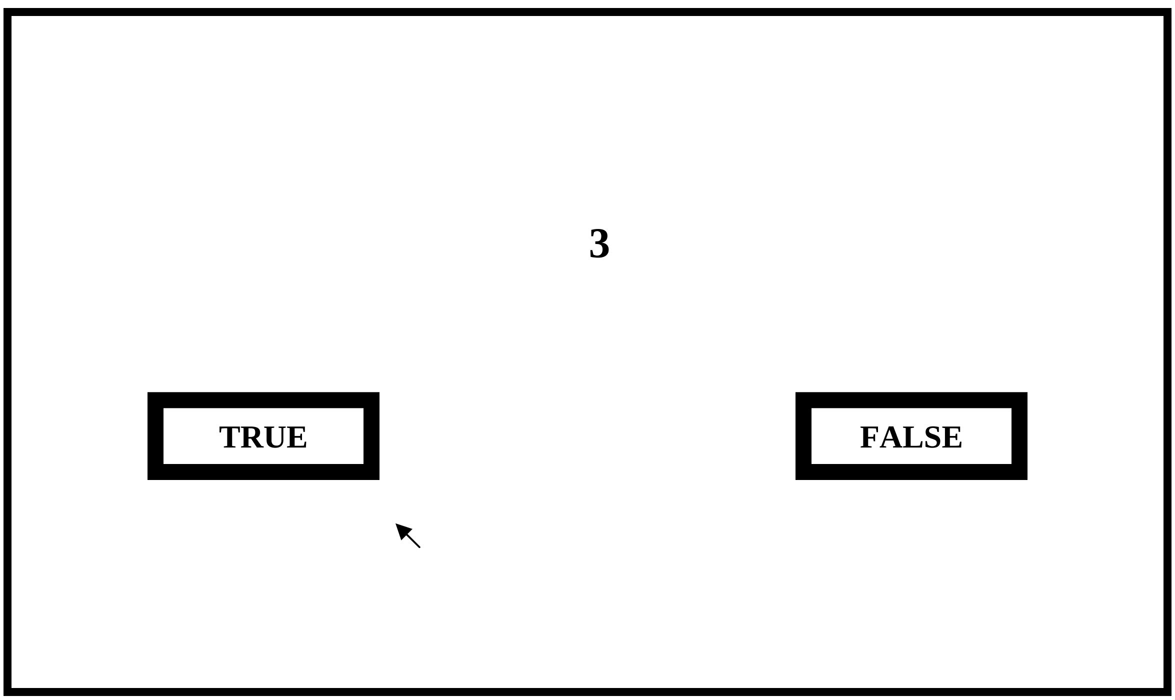
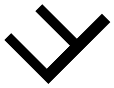


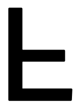
Figure 5
Illustration of one of the math problems presented in the OSPAN

You would see:



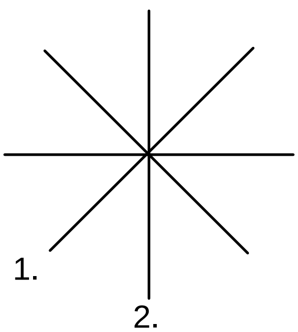
Say “normal”

Then you would see:



Say “mirror-imaged”

You would record on your answer sheet grid:



Only the capital letters F, L, J, P, and R were used. They appeared as:

F L J P R

Figure 6
Illustration of the letter Rotation Task

Appendix A: *Announcement*

The purpose of this study is to investigate the impact of second language proficiency on working memory capacity in early adulthood. This study involves a one-hour session at the Computer Lab - 203 Williams Hall. You will first be asked to fill out an online survey that would basically give the researchers an idea of your demographic background as well as your second language proficiency. Then, you will be asked to translate some short sentences from and to the second language you know. Next, both your verbal working memory capacity and your visuospatial working memory capacity will be assessed via 2 computer-based tasks.

__Appendix B__

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Informed Consent for Participant of Investigative Project

Title of Project: "Language and Working Memory Capacity in Early Adulthood: Contributions from First and Second Language Proficiency"
Investigators: Hossam Zaki, MS & Martha Ann Bell, PhD

I. Purpose of this Research

You have been invited to be a part of a research study on the impact of language on working memory capacity. What we learn from this study will help us better understand whether acquiring a second language helps in enhancing individuals' working memory capacity. We are recruiting 100 participants whose native language is English and who demonstrate a wide range of abilities in one of the following SEVEN languages: Chinese, French, German, Japanese, Russian, Spanish, or Arabic.

II. Procedures

This study involves a one-hour session (divided into 4 main parts) with you in the computer lab located in 203 Williams Hall. After signing this consent form, you will be asked to log into one of the computers to start the first part, which is intended to collect general demographic data (e.g. age, gender, etc.) and some information regarding your English verbal proficiency as well as your second language proficiency. Then, you will be asked to translate three sentences from the English language to the language that you know and three sentences vice versa using a paper and a pencil. DON'T'WORRY! We are looking for individuals with a wide range of second language proficiency. So, if you know just a little bit of any of the languages mentioned above, we want you. Of course, if you are bilingual we need you as well. Once you are done with the questionnaire part, you will complete two working memory tasks (verbal and visuospatial). Each of these working memory tasks will take about 15-20 minutes to finish.
The tasks are not tiring, but you are welcome to take a rest break between the two tasks.

III. Risks

There are no known risks to the subjects of this study.

IV. Benefits of This Research

No guarantee of benefits has been made to encourage you to participate. However, by being a part of this research, you will help in learning more about working memory and language during early adulthood. You will also get one extra credit point for your designated course.

V. Extent of Anonymity and Confidentiality

The results of this study will be kept strictly confidential. The information you provide will have just your subject number which will identify you during analyses and any written reports of the research. Only Mr. Zaki and Dr. Bell will have access to these data.

VI. Compensation

Your participation is voluntary and unpaid. However, you will earn one extra credit point via the Sona systems for your participation.

VII. Freedom to Withdraw

You are free to withdraw from this study at any time for any reason. You will still receive the one extra credit point.

VIII. Approval of Research

The Institutional Review Board for projects involving human subjects at Virginia Polytechnic Institute and State University and the Department of Psychology has approved this research.

IX. SUBJECT'S RESPONSIBILITIES AND PERMISSION

I voluntarily agree to participate in this study, and I know of no reason I cannot participate. I have read and understood the informed consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project. If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

____________________________ Signature	____________________________ Date
____________________________ Name (please print)	____________________________ Contact: Phone/address/e-mail (optional)

Should I have any questions about this study, I may contact:

1) Hossam Zaki, MS
   Investigator, Graduate Student in Psychology, 231-1116
2) Martha Ann Bell, PhD
   Investigator, Associate Professor of Psychology, 231-2546
3) David W. Harrison, PhD
   Chair, Psychology Department Human Subjects Committee, 231-4422
4) Dr. David Moore
   Chair, IRB, CVM Phase II 231-4991

<u>Appendix C:</u> *On-line Survey (Participant Information Sheet)*

Personal Information

Please respond to all of the following carefully.

Your accurate responses will greatly help in the analysis of the final data.

Please note all information will remain anonymous and confidential.

Thanks in advance for your participation.

Please Enter Your assigned number in the box below

Gender

- Male
- Female

Age

- younger than 18
- 18-19
- 19-20
- 20-21
- 21-22
- older than 22

I'm a

- Freshman
- Sophomore
- Junior
- Senior

My Major is:

My Native Language is English

- Yes
- No

My second language is:

- Chinese
- French
- German
- Japanese
- Russian
- Spanish
- Arabic

I learned my second language

- At school
- At home
- I traveled abroad
- Peer (friends) Interaction
- I used self-learning methods (e.g. books, tapes, etc.)

other (please specify):

I first learned my second language when I was

- At the age of 6 years or younger
- Between the ages of 6 and 12
- Older than 12 years of age

I would describe my Second Language reading skill as

Excellent Very Good Good Fair Poor

I would describe my Second Language writing skill as

Excellent Very Good Good Fair Poor

I am bilingual

- Yes
- No

I know a third language.

☐ NO

Yes (please specify) ______

My cumulative GPA is

- 4.0
- 3.5 -3.9
- 3.0-3.4
- 2.5-2.9
- 2.0-2.4

Verbal Test (Part I)
<u>Sentence Completion</u>

1) The revolution in art has not lost its steam; it ____ on as fiercely as ever.

- A. trudges
- B. meanders
- C. edges
- D. ambles
- E. rages

2) Each occupation has its own ____ ; bankers, lawyers and computer professionals, for example, all use among themselves language which outsiders have difficulty following.

- A. merits
- B. disadvantages
- C. rewards
- D. jargon
- E. problems

3) ____ by nature, Jones spoke very little even to his own family members.

- A. garrulous
- B. equivocal
- C. taciturn
- D. arrogant
- E. gregarious

4) Biological clocks are of such ____ adaptive value to living organisms, that we would expect most organisms to ____ them.

A. clear - avoid

B. meager - evolve

C. significant - eschew

D. obvious - possess

E. ambivalent - develop

5) The peasants were the least ____ of all people, bound by tradition and ____ by superstitions.

A. free - fettered

B. enfranchised - rejected

C. enthralled - tied

D. pinioned - limited

E. conventional - encumbered

6) In the Middle Ages, the ____ of the great cathedrals did not enter into the architects' plans; almost invariably a cathedral was positioned haphazardly in ____ surroundings.

A. situation - incongruous

B. location - apt

C. ambience - salubrious

D. durability - convenient

E. majesty - grandiose

7) If there is nothing to absorb the energy of sound waves, they travel on ____ , but their intensity ____ as they travel further from their source.

A. erratically - mitigates

B. eternally - alleviates

C. forever - increases

D. steadily - stabilizes

E. indefinitely - diminishes

8) The two artists differed markedly in their temperaments; Palmer was reserved and courteous, Frazer ____ and boastful.

A. phlegmatic

B. choleric

- C. constrained
- D. tracTable
- E. stoic

9) The intellectual flexibility inherent in a multicultural nation has been ____ in classrooms where emphasis on British-American literature has not reflected the cultural ____ of our country.

- A. eradicated - unanimity
- B. encouraged - aspirations
- C. stifled - diversity
- D. thwarted - uniformity
- E. inculcated - divide

10) The conclusion of his argument, while ____ , is far from ____ .

- A. stimulating - interesting
- B. worthwhile - valueless
- C. esoteric - obscure
- D. germane - relevant
- E. abstruse - incomprehensible

Verbal Test (Part II)
Definitions

1. inscribe =

- (a) to go about with a small stock of goods to sell
- (b) to cause to burst in pieces by force from within
- (c) to enter in a book or on a list, roll or document by writing
- (d) to Take in a wrong sense

2. undulate =

- (a) to move like a wave or in waves
- (b) to expurgate in editing (a literary composition) by omitting words or passages
- (c) to delay or put off to some other time
- (d) to clear away or provide for, as an objection or difficulty

3. narrate =

- (a) to tell a story
- (b) to deprive of weapons
- (c) to place the products or merchandise of under a ban
- (d) to debar

4. presage =

- (a) to foretell
- (b) to prevent from being disclosed or punished
- (c) to begin to develop into an embryo or higher form
- (d) to be violently excited or agitated

5. recede =

- (a) to move back or away
- (b) to make indigent or poor
- (c) to remunerate
- (d) to harden or toughen by use, exercise or exposure

6. bide =

- (a) to come into view or into existence
- (b) to send trough or across
- (c) to await
- (d) to disclaim responsibility for

7. annotate =

- (a) to show or prove to be involved in or concerned
- (b) to cut off or cut short
- (c) to stretch out or expand in every direction
- (d) to make explanatory or critical notes on or upon

8. befog =

- (a) to harass with persistent demands or entreaties
- (b) to confuse
- (c) to convey, remove or cause to pass from one person or place to another
- (d) to delegate authority to

9. intromit =

- (a) to diminish the gravity or importance of
- (b) to express, formulate or exemplify in a concrete, compact or visible form
- (c) to insert
- (d) to perceive by taste or smell

10. chastise =

- (a) to win confidence or good graces for oneself
- (b) to fail to put strongly enough, as a case
- (c) to subject to punitive measures
- (d) to train to obedience

END OF SURVEY

PLEASE CLICK THE SUBMIT BUTTON

Appendix D: *Example of the translation sheet*

Please Enter Your Assigned number here

Part I

Please translate the following 3 sentences into English. Use the space below each sentence for your translation.

1) 那个男孩每天都去上学。

---

2) 你最近读了哪本书？

---

3) 如果我早知道他要去那个晚会，我就确定也一起去了。

Part II

Please translate the following 3 sentences into Chinese. Use the space below each sentence for your translation.

1) The ice melts quickly.

---

2) Could you tell me where the nearest restaurant is?

---

3) Susanne wanted to be here, but she cannot come because her car is in the shop.

VITAE

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Experience

1993–1994 Middle school Cairo, Egypt
Teacher
- Teaching English Language.

1994–2000 Helwan University Cairo, Egypt
Teaching Assistant
- Educational Psychology.

Fall 2004 Virginia Tech Blacksburg, VA
Instructor
- Developmental Psychology (PSYC 2034)

Spring 2005 Virginia Tech Blacksburg, VA
Instructor
- Developmental Psychology (PSYC 2034)

Education

1989–1993 Helwan University Cairo, Egypt
- B.A. (English Literature and Education)

1993-1995 Helwan University Cairo, Egypt
- Diploma (Educational Psychology)

2002 Virginia Tech Blacksburg, VA
- MA (Curriculum and Instruction – Non-thesis)

Advisor: Peter Doolittle, PhD

2004 Virginia Tech Blacksburg, VA
- MS (Psychology)

"Language as a mediator between home environment and prefrontal functioning"
Advisor: Martha Ann Bell, PhD

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- PhD (Psychology)

"Language and working memory capacity in early adulthood: Contributions from first and second language proficiency"
Advisor: Martha Ann Bell, PhD