Working Memory, First Language, Second Language, and Mathematics: A Study of Relations

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Abstract

This study investigates the relationship among working memory (WM), first language (L1), second language (L2), and mathematics; with an aim to understand whether achievement in mathematics and L1 is related to performance in later L2 learning; and if so, whether WM components (i.e. phonological loop and central executive) play a role in this relationship between mathematics and language. A second objective of this study was to devise a computerized Turkish Reading Span Task. The participants were 60 university students. The data were collected quantitatively through 4 measures. To measure WM components, a computerized Turkish Reading Span Task and a Digit Span Task; to measure achievement in mathematics and L1, Transition to Higher Education Examination scores; and to measure achievement in L2, the preparatory school exam scores were used. Correlation analyses were performed via SPSS Version 18. The data analysis revealed (1) a relation of mathematical achievement to performance in L2 learning; and (2) a relation of achievement in L1 to performance in L2 learning. The findings indicate that achievement in mathematics and L1 is related to performance in later L2 learning, and WM is a significant factor in terms of the relationship between language and mathematics. In particular, the specific functions of the phonological loop are of pivotal importance for L2 and mathematics – but not for L1; whereas the specific functions of the central executive play more crucial role in L1 and L2 – but not in mathematics.

Keywords: working memory, first language, second language, mathematics, Turkish Reading Span Task

Introduction

Language and mathematics are domain-specific abilities which require higher-order cognitive functions that are unique to humans. Although first language (L1) is learned by all typically developing children, and is acquired without explicit teaching; a later foreign/second language (L2) after childhood can only be learned through extensive teaching. Just as for learning L2, a specialized and intensive education is also required for the development of mathematical skills. A crucial domain-general cognitive mechanism that has been constantly associated with cognitive functions like language and mathematics is working memory (WM). Conway, Jarrold, Kane, Miyake, and Towse (2008) state that WM is “fundamentally a form of memory, but it is more than memory, for it is ‘memory at work’ encompassing a number of components that perform several cognitive functions responsible for the storage and the
executive control of information” (p.3). Alloway (2006) asserts that WM plays a key role in supporting children’s learning over the school years, and beyond this into adulthood. This means that a domain-general ability like WM seems to be closely related to domain-specific abilities like mathematics (Alloway & Passolunghi, 2011; Holmes & Adams, 2006; Raghubar, Barnes, & Hecht, 2010) and language (Fuchs et al., 2005, 2008, 2010; Purpura, Hume, Sims, & Lonigan, 2011). In some studies, general language skills seem to be the predictor of, and related to, a variety of mathematical performance across different age groups (Hooper, Roberts, Sideris, Burchinal, & Zeisel, 2010; Purpura et al., 2011). In their study, for instance, Reimann, Gut, Frischknecht, and Grob (2013) have shown that deficits in general language skills or WM can often co-occur and result in broader impairment in mathematical functioning. In their review, Raghubar et al. (2010) also conclude that WM is indeed related to mathematical performance in adults and in typically developing children; and cognitive functions like language might mediate or moderate the relations between WM and mathematics.

Background to the Study

The most influential WM model has been that of Baddeley and Hitch’s (1974) WM model. In their model, they proposed a WM model comprising of three components: the central executive (CE), and two slave systems: the phonological loop (PL) and the visuo-spatial-sketchpad (VSSP). The CE was represented as a control system of limited attentional capacity that is responsible for the manipulation of information within WM and for controlling two subsidiary storage systems: the PL and the VSSP. The PL was assumed to be responsible for the storage and maintenance of information in a phonological form, while the VSSP was dedicated to the storage and maintenance of visual and spatial information (Repovš & Baddeley, 2006). Based on a number of empirical findings a fourth component, the episodic buffer (EB), was later added to the model (Baddeley, 2000). The EB is assumed to be a limited capacity store that is capable of multi-dimensional coding, and that allows the binding of information to create integrated episodes. Overall, WM is viewed as a comprehensive system that unites various short- and long-term memory (STM/LTM) subsystems and functions (Baddeley, 1986).

As regards the research carried out with an aim to investigate the relationship between WM and academic achievement in various subjects; it is clear that WM plays a prominent role in mathematical achievement of children (Holmes & Adams, 2006; Miller & Bichsel, 2004; Purpura & Ganley, 2014; Smedt et al., 2009; Zheng, Swanson & Marcoulides, 2011). Other empirical investigations have consistently implicated WM as a central deficit in children with mathematical disabilities (Andersson & Lyxell, 2007; D’Amicoa & Guarnera, 2005; McLean & Hitch, 1999; Peng, Congying, Beilei & Sha, 2012).

Regarding first/native language (L1), WM also plays a fundamental role in children in terms of vocabulary (Baddeley, Gathercole & Papagno, 1998; Gathercole, Service, Hitch, Adams, & Martin, 1999; Gathercole, Willis, Emslie, & Baddeley, 1992); and spoken language (Adams & Gathercole, 2000); and in adults in terms of verbal achievement (Daneman & Carpenter, 1980; Friedman & Miyake, 2004); and reading comprehension (Cohen-Mimran & Sapir, 2007; Turner & Engle, 1989).

Second/foreign (L2) language and WM is also related in terms of vocabulary acquisition (Gupta & MacWhinney, 1997; Masoura & Gathercole, 1999, 2005), reading comprehension (Alptekin & Ergçetin, 2010; Daneman & Carpenter, 1980; Payne, Kalibatseva & Jungers, 2009; Turner & Engle, 1989); listening comprehension (McInnes, Humphries, Hogg-Johnson
& Tannock, 2003); speech production (Finardi & Prebianca, 2006; Fortkamp, 1999); written language production (Kellogg, Olive & Piolat, 2007; Swanson & Berninger, 1996) and overall language proficiency (Gilabert & Muñoz 2010; Kormos & Sáfár, 2008).

The current study

Despite this large number of studies investigating the relationship between WM, language, and mathematical achievement; they have certain limitations which need further research. First of all, in terms of the relationship between mathematical achievement and WM, most of the studies are carried out with young children (at primary school), very young children (4-5 years old), or children with specific disorders. Secondly, while the CE is generally found to be influential in mathematical achievement, the role of the PL remains unclear. Some studies support the role of the PL (Andersson & Lyxell, 2007; Peng, et al. 2012; Rasmussen & Bisanz, 2005; Zheng, et al. 2011); whereas others claim that the PL is not the major factor in explaining arithmetical difficulties (D’Amicoa & Guarnera, 2005; Holmes & Adams, 2006; McLean & Hitch, 1999).

Concerning the relationship between WM and L2, studies are relatively fewer and the findings about the relation between the PL and L2 are controversial. For example, in some studies, the measures of the PL (i.e. simple span tasks, such as digit or word span) do not correlate with language measures (Daneman & Carpenter, 1980; Turner & Engle, 1989); whereas in other studies it does (Baddeley, Papagno & Vallar, 1988; Masoura & Gathercole, 1999, 2005). Besides, measures of the CE (i.e. complex span tasks, such as Reading Span Task or Operation Span Task) also show, though rarely, non-significant correlations with language skills. For example, in Fortkamp’s (1999) study, Speaking and Reading Span Tests did not correlate with any L2 fluency task.

As for the relationship between L1 and L2, Palladino and Cornoldi (2004) assert that children with foreign language learning difficulties typically seem to have problems with L1 learning; and Hulstijn and Bossers (1992) also support the relationship between L1 and L2 achievement. Besides, the studies on the relationship between language and mathematics are usually carried out with young or very young children, and they usually investigate the early-developmental stages of L1 and mathematics, or L2 and mathematics. In other words, the number of studies done with young adults who are beyond the acquisition process of L1 and advanced concepts in mathematics are limited. Furthermore, the studies investigating the relationship among L1, L2, mathematics, and WM are scarce.

Therefore, this study tries to contribute to this research stream by exploring the relationship among WM, language, and mathematics in young adults. To this end, our first aim is to find out whether general achievement in mathematics and L1 is related to the performance of later L2 learning in young adults (i.e. preparatory school students at university), whose first/native language is Turkish (L1) and who have started to learn English as their second/foreign language (L2). The second aim is to explore whether there is a relationship between WM components (namely the PL and the CE) and achievement in L1, L2, and mathematics.

Method

Participants

60 voluntary students (24 males and 36 females) participated in this study. Their ages ranged from 18 to 23 (M = 19.55; SD = 1.17). They were students in an English preparatory school of a university in Turkey. The first/native language (L1) of all students was Turkish. All participants were classified as monolingual on the basis of a questionnaire examining their
language history. They all started learning English as a foreign language (L2) in the preschool and they were at elementary (CEFR A1) level. Participants gave their written informed consent prior to their inclusion in the study.

**Measures**

**Digit span task (DSPAN).** In this task, the participants were presented with a series of digits, beginning with three digits (e.g., 8, 3, 4) and then they were immediately required to recall the digits in the order they were presented. When they did this successfully, they were given a longer list (e.g., 9, 2, 4, 0). The length of the longest list a person could remember was that person's digit span. In this study, a computerized version of the DSPAN (www.cambridgebrainsciences.com) was administered to the participants in a computer lab by the researcher, who informed the participants and showed them a demo before they did the task.

**Reading span task (RSPAN).** Different from the original RSPAN of Daneman and Carpenter (1980), a revised and computerized version of this RSPAN was created from scratch in this study. The sentences were written in Turkish – not translated - and the number of the words in sentences ranged from 14 to 17. The number of letters in these sentences ranged from 91 to 98.

In the original RSPAN, the participants were required to remember the last words of each sentence. Newer RSPAN tasks (see Conway et al. 2005; Kane et. al, 2004; Sanchez et. al, 2010; Unsworth, Heitz, Schrock, & Engle, 2005) require participants to recall unrelated letters instead of the last words of the sentences. Therefore the RSPAN devised specifically for this study also required participants to remember (consonant) letters (i.e. F, G, T, Z, etc.) instead of words.

Additionally, grammaticality judgment was ensured. Of 60 sentences, half was written sensical and half nonsensical so that the participants had to determine whether the sentence was sensical or nonsensical. As an example, whereas “Yaşlı adam balkonda oturmuş yudumlarken, birden karşı apartmandan bir çocuğun kendisine el salladığını farketti.” (As the old man was sitting on his balcony and sipping his tea, he realized a boy waving at him from the opposite house) is a sensical sentence; “Sabahları erken kalkıp evimizin karsısındaki yemyesil tepside yürüyüs yaptığım zaman kendimi çok iyi hissediyorum.” (I feel myself very good when I get up early and take a walk in the very green tray opposite our house) is nonsensical. Nonsensical sentences were created by simply changing one word (e.g. “park” to “tray”) from an otherwise meaningful sentence. There are many studies which use sensicality judgement in their studies (Alptekin & Erçetin, 2010; Conway et al. 2005; Kane et. al, 2004; Sanchez et. al, 2010; Unsworth et al., 2005).

Finally, the RSPAN was devised as a computer program so that a time restriction (maximum 7 seconds for each sentence) could be ensured. This computerized and Turkish version of the RSPAN was administered to the participants in a computer lab by the researcher who informed them and showed a demo to them before they did the task.

The procedure was approved by the Ethics Committee of the University.

**L1 and mathematics.** To measure their achievement in L1 (Turkish) and mathematics, the participants’ scores in Transition to Higher Education Examination were used. It is a standardized exam for the admission to higher education in Turkey administered by Measuring, Selection and Placement Center. The only way to enter a university in the Turkish education system is through this exam, in which there are 4 subject areas; namely, Turkish,
Social Sciences, Mathematics, and Physical Sciences; and 40 multiple choice type questions each.

In the Turkish component of the Transition to Higher Education Examination (THEET from here afterwards) there are 40 multiple choice questions, assessing the students’ verbal ability in their L1. The content of the questions are based on grammar, vocabulary, and reading. Listening, writing, and speaking skills are not measured in this exam.

In the Mathematic component of the Transition to Higher Education Examination (THEEM from here afterwards) there are 40 questions assessing the students’ ability in advanced concepts of mathematics and geometry.

L2. To measure their L2 (English) verbal achievements, the participants’ Achievement Exam (AE) scores at the preparatory school were used. This exam is administered once at the end of each term. It comprises of reading, writing, listening and use of English parts and in total accounts for 100 points. However, because the content of the questions in THEET is based on grammar, vocabulary, and reading; only the grammar, vocabulary and reading parts of AE were taken into account.

Results
In this part, firstly, the descriptive statistics will be provided for all measures (RSPAN: Reading Span Task, DSPAN: Digit Span Task, THEET: Transition to Higher Education Examination Turkish Component, THEEM Transition to Higher Education Examination Mathematics Component, and AE: Achievement Exam).

In the second part of this section, in order to describe the strength and direction of the linear relationship between the measures, the results from the analyses of Pearson product-moment correlation coefficients ($r$) will be presented.

General Descriptive Statistics
Descriptive statistics for the results of RSPAN, DSPAN, THEET, THEEM, and AE measures are provided in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSPAN</td>
<td>43.18</td>
<td>10.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSPAN</td>
<td>7.54</td>
<td>1.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>THEET</td>
<td>34.81</td>
<td>2.94</td>
<td>25</td>
<td>40</td>
</tr>
<tr>
<td>THEEM</td>
<td>29.52</td>
<td>6.61</td>
<td>14</td>
<td>40</td>
</tr>
<tr>
<td>AE</td>
<td>75.00</td>
<td>11.59</td>
<td>51.50</td>
<td>97.50</td>
</tr>
</tbody>
</table>

Correlation Analyses
Figure 1 below presents the results from Pearson product-moment correlation analysis, which was computed to assess the relationship between all variables. There were significant, positive, and from moderate to strong correlations between all variables except for RSPAN-THEEM, DSPAN-THEET, and THEET-THEEM.
Discussion

WM and L2: The role of the CE

This study reveals a positive and moderate correlation between RSPAN and AE, which supports the claim that the CE component of WM plays an important role in L2 achievement. As Daneman and Carpenter (1980) agree, the CE processes are probably one of the principal factors determining individual differences in WM span. In one of his recent papers in 2012, Baddeley analyzes these CE processes by proposing four suggestions about the functions of the CE (p. 14):
- focusing attention
- dividing attention between two important targets or stimulus streams
- switching between tasks
- interfacing with LTM

These functions of the CE clearly relate to nearly all skills in L2 processing in WM. Hence, it could be suggested that the correlation found between RSPAN and AE in this study evidently reflects the relationship between the CE functions and L2 processing in WM.

WM and L2: The role of the PL

This study also shows positive and moderate correlation between DSPAN and AE. Baddeley et al. (1998) state that the DSPAN measure provides a useful indication of the capacity of an individual's PL (p. 18). As Baddeley (1998) states, “the PL correlates with the more conventional measure of digit span” (p. 236). The PL involves “a sub-vocal rehearsal process” which means silently maintaining the contents of the phonological store (Baddeley, et al., 1998, p. 167). When answering questions in L2, it is obvious that the participants need to use this inner-speech function of the PL in order to make sense of the questions they answered, which also explains the positive and moderate correlation found between DSPAN and AE (i.e. the PL and L2) in this study.

WM and L1: The role of the CE
As shown in Figure 1, there is a positive and moderate correlation between RSPAN and THEET (i.e. the CE and L1). Since both THEET and AE measure the same content areas (reading, grammar and vocabulary), the relationship found between the CE and L2 achievement, thus, is also apparent in the relationship found between the CE and L1 achievement in this study.

**WM and Mathematics: The role of the PL**

In the present study, we found a strong correlation between DSPAN and THEEM (i.e. the PL and Mathematics).

The correlation between the PL and mathematics might be traced to the interface function of the PL to LTM. As Baddeley (2012) states, information flows from LTM to the PL, as well as the reverse (p. 11). From this reciprocal relationship between the PL and LTM, it follows that, unlike very young children, since most adults readily know the answer to the sum 6+7 or the product 3x4, without having to follow any form of calculation algorithm, the answers to these problems are calculated and found by direct LTM access (Logie, Gilhooly & Winn, 1994).

The finding of this study that there is relationship between the PL and mathematics is also consistent with those of Andersson and Lyxell (2007), Peng, et al. (2012), Rasmussen and Bisanz (2005), and Zheng, et al. (2011).

**WM and Mathematics: The role of the CE**

Despite the fact that RSPAN and DSPAN (i.e. the CE and the PL) are strongly correlated with each other, THEEM showing correlation only to DSPAN but not to RSPAN is noteworthy (Figure 1). It is generally accepted that number-based WM span measures are more strongly associated with mathematics than non-numerical span measures, such as those that use words (i.e. RSPAN in this study). One explanation is that, as Holmes and Adams (2006) explain, WM and mathematics are linked because the assessments of both involve either number processing or direct access to numerical information (p. 343). Since the RSPAN measure in this study consisted of only words and letters, this fact might explain the reason why there was no correlation between RSPAN and THEEM (i.e. the CE and Mathematics).

**Is there a relationship between L2 and Mathematics?**

As shown in Figure 1, the correlation analyses in the present study revealed a high and positive correlation between THEEM and AE (i.e. Mathematics and L2), which means that there is a strong relationship between mathematical achievement and later L2 learning. At this point it is important to note that, in the data analyses of the present study, while L2 achievement showed relationship both with the CE and the PL measures of WM; mathematical achievement showed relationship only with the PL measures of WM (Figure 1). Taking the previous discussions about these relationships into consideration; the most important result to be drawn in terms of the relationship between L2 achievement and mathematical achievement is that the role of the PL is critically important in both L2 and mathematical achievement, which means that the PL might play a more prominent role than the CE in the relationship among WM, mathematics, and L2.

**Is there a relationship between L2 and L1?**

The data analyses in the present study showed a positive and moderate correlation between AE and THEET scores (i.e. L2 and L1). The correlation found between L1 and L2 (Figure 1) might indicate that the cognitive functions while processing the first language may have an impact on the learning processes of the second language. Here, the question arises whether this relation is language-specific or not. Since the typologies of Turkish and English are different, it can be argued that a transfer from Turkish (L1) to English (L2) does not seem
possible. This means that a domain-general ability like WM appears to be closely related to the domain-specific ability of language, regardless of the typology of the languages.

**Is there a relationship between L1 and Mathematics?**

As it can be seen in Figure 1, no correlation was found between THEET and THEEM, which means that there is no meaningful relationship between L1 and Mathematics. Taken together, we found relations of (1) the CE to L1 and L2; (2) the PL to L2 and mathematics; (3) L2 to mathematics; and (4) L1 to L2. This means that the CE plays a role in the relationship between L1 and L2, but not in L2 and mathematics. On the other hand, the PL plays a role in the relationship between L2 and mathematics, but not in L1 and L2. Therefore, it can be inferred that the reason why there was no correlation between L1 and mathematics in this study might be traced to the role of the PL.

**Conclusion**

In this correlational study, we investigated the relationship among WM and achievement in L1, mathematics, and L2. The main aim of the study was to find out whether WM components and the achievement in mathematics and L1 are related to performance in later L2 learning in young adults who are beyond the acquisition process of L1 and of advanced concepts in mathematics. The data analysis revealed (1) a relation of mathematical achievement to performance in L2 learning; and (2) a relation of achievement in L1 to performance in L2 learning. These results indicate that achievement in mathematics and L1 is related to performance in later L2 learning – regardless of the typology of the languages. In addition, WM has been shown to be a significant factor in terms of the relationship between language and mathematics. In particular, the specific functions of the PL are of pivotal importance for L2 and mathematics – but not for L1; whereas the specific functions of the CE play more crucial role in L1 and L2 – but not in mathematics.

Overall, we conclude that achievement in mathematics and L1 seems to be associated with performance in later L2 learning; and WM components appear to underlie each of these high-order cognitive processes.

**Implications**

These results have several implications in terms of WM and academic achievement in general. Shipstead, Hicks and Engle (2012) state that if WM capacity limits performance in academic areas, then a training program that increases WM capacity should result in improvements in these areas. Although the studies carried out to find out whether WM capacity could be improved by training are relatively recent (Holmes & Adams, 2006; Klingberg, Forssberg, Westerberg, 2002; Klingberg, et al., 2005), they seem promising. In their comprehensive review, Morrison and Chein (2011), for example, concluded that WM training can be considered as a tool to enhance general cognitive abilities.

The findings in this study indicate that the growth of WM components (especially the PL in line with the results of the present study) might result in an increase in achievement of language and mathematics. Therefore, we believe that training WM and thus increasing the capacity of its components would also increase achievement in mathematics and language.
References


