The role of strategy choice and working memory capacity in arithmetic acquisition in third grade primary school children

Dijana Mirkovic
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The Role of Strategy Choice and Working Memory Capacity in Arithmetic Acquisition in Third Grade Primary School Children

Dijana Mirkovic
Edith Cowan University

A Thesis Submitted in Partial Fulfilment of the Requirements for the Award of Bachelor of Arts (Psychology) Honours

Faculty of Community Studies, Education and Social Sciences, Edith Cowan University.

October, 2005

I declare that this written assignment is my own work and does not include:

(i) material from published sources used without proper acknowledgement; or

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Signed:
Declaration

I certify that this literature review and research project does not incorporate, without acknowledgment, any material previously submitted for a degree or diploma in any institution of higher education and that, to the best of my knowledge and belief, it does not contain any material previously published or written by another person except where due reference is made in the text.

Signature: 

Date: 19-04-2006
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Table of Contents

Title Page .................................................................................................................. i
Declaration ................................................................................................................ ii
Acknowledgments .................................................................................................... iii
Table of Contents .................................................................................................... iv
List of Tables ........................................................................................................... v

Title Page Literature Review .................................................................................... 1
Abstract Literature Review ........................................................................................ 2
Introduction ................................................................................................................ 3
  Developmental Influences in Arithmetic Ability ...................................................... 4
  The Role of Strategy Choice in Arithmetic Ability of Addition ................................ 6
  The Role of Strategy Choice in Ability to Solve Multiplication Problems .......... 12
  Working Memory Capacity and Arithmetic Ability ............................................... 15
Conclusion ................................................................................................................ 19
References .................................................................................................................. 22

Title Page Research Report ....................................................................................... 28
Abstract Research Project .......................................................................................... 29
Introduction ................................................................................................................ 30
  Developmental Influences ....................................................................................... 30
  Strategy Choice in Arithmetic Ability ..................................................................... 32
  The Influence of Working Memory Capacity on Arithmetic Ability .................. 35
Method ....................................................................................................................... 37
  Participants ............................................................................................................. 37
  Design .................................................................................................................... 38
  Materials ................................................................................................................ 38
    The Working Memory Capacity for Sentences ..................................................... 39
    The Working Memory Capacity for Digits ........................................................... 39
    The Working Memory Capacity for Objects ........................................................ 39
  Procedure .............................................................................................................. 40
Results ....................................................................................................................... 41
  Data Screening and Accuracy ................................................................................ 41
  Strategies Selected for 10 Addition Problems ....................................................... 41
  Chi Squared Test for Goodness of Fit Analysis ..................................................... 42
  Bivariate Correlation Analysis ............................................................................. 43
  Multiple Regression Analysis ............................................................................... 44
Discussion ................................................................................................................. 45
  The Relationship Between Strategy Selection and Addition Ability .................. 45
  The Relationship Between Strategy Selection and Multiplication Ability .......... 48
  The Relationship between Working Memory Capacity and Multiplication Ability 49
  Limitations and Methodological Implications of the Present Study .................... 49
  Implications for Future Research ........................................................................ 50
Conclusion ............................................................................................................... 51
References ............................................................................................................... 53
<table>
<thead>
<tr>
<th>Appendices</th>
<th>Information Letter (Principal)</th>
<th>Information Letter (Parents)</th>
<th>Consent Forms</th>
<th>Verbal Consent Letter</th>
<th>Multiplication Problems</th>
<th>Addition Problems</th>
<th>Individual Results Sheets</th>
<th>Working Memory Capacity (Sentences)</th>
<th>Working Memory Capacity (Digits)</th>
<th>Working Memory Capacity (Objects)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appendix A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>58</td>
<td>60</td>
<td>62</td>
</tr>
<tr>
<td>Appendix B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>63</td>
</tr>
<tr>
<td>Appendix C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>64</td>
</tr>
<tr>
<td>Appendix D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>65</td>
</tr>
<tr>
<td>Appendix E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>66</td>
</tr>
<tr>
<td>Appendix F</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>67</td>
</tr>
<tr>
<td>Appendix G</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>69</td>
</tr>
<tr>
<td>Appendix H</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>70</td>
</tr>
</tbody>
</table>
List of Tables

Table 1  Number of Addition and Multiplication Problems Solved Correctly........ 41
Table 2  Mean Scores for Strategies Selection for Addition Problems..................... 42
Table 3  Frequency of Strategy Selection in 0-50% Correct Addition Solutions and
50-100% Correct Addition Solutions........................................................................ 42
Table 4  Correlation Coefficients for the Six Measures.......................................... 43
The Role of Strategy Choice and Working Memory Capacity in Arithmetic Acquisition in Primary School Children

A Review of the Literature

Dijana Mirkovic
Abstract
This review examines the question of what determines arithmetic ability in primary school children. It has been suggested that arithmetic ability is mediated by many factors such as developmental factors, exposure to arithmetic facts, selection and utilisation of various strategies when solving arithmetic problems, and individual differences in working memory capacity. Some theories suggest that factors such as the complexity of a problem affect the selection of strategies when solving simple arithmetic problems such as addition, whereas other theories propose that individual differences in working memory capacity play a prominent role in arithmetic ability. Research is discussed that provides support for both theories. Further research is proposed that would reconcile these apparent contradictions.

Student: Dijana Mirkovic
Supervisor: Dr Craig Speelman
22, August, 2005
The Role of Strategy Choice and Working Memory Capacity in Arithmetic Acquisition in Primary School Children

Most people depend on mathematical skills in their everyday lives in order to be able to tell time and dates, deal with money, count objects, and to calculate distances between places. An inability to apply mathematical skills would result in many difficulties in a society that relies on the ability to utilise numeric skills. The importance of the ability to solve arithmetic problems and the impact on academic self concept in children has been implied in research conducted by Hay, Ashman, van Kraayenoord and Stewart (1999). The results of this study suggested low achievement in mathematics resulted in reduced self-concept, thus having an impact on other academic fields and academic self-concept. This research highlights the importance of understanding the skills required to improve mathematical achievement and the need to understand the underlying cognitive processes involved in arithmetic.

An important question in the development of mathematical abilities is how people acquire the ability to solve arithmetic problems and how they transfer basic arithmetic skills such as addition to more complex problems such as multiplication. It is generally agreed that children use a mixture of memory retrieval and various algorithmic procedures when solving arithmetic problems (Butterworth, Zorzi, Girelli, & Jonckheere, 2001). This paper reviews research that has investigated arithmetic ability in primary school age children and the transfer of simple arithmetic skills such as addition to more complex arithmetic problems such as multiplication. It also examines the role of working memory capacity in arithmetic ability. The emphasis of the review will be to consider whether the development of specific skills and strategies in arithmetic skill acquisition for simple addition, or individual differences
in working memory capacity, play a more prominent role in the ability to perform multiplication.

Developmental Influences in Arithmetic Ability

The psychological research areas of cognitive psychology and educational psychology investigate how people acquire arithmetic skills, how they acquire basic concepts of mathematics, and the cognitive processes that underlie these acquisitions (Pintrich, 1994). In contrast to some researchers (e.g., Butterworth, 2005; Gelman & Meck, 1983) who argue that all children have some innate arithmetic skills, most psychologists would support the idea that many environmental factors including social and economic factors can contribute to individual differences in the ability to understand arithmetic principles and can shape children’s performance (Browne-Miller, 1994; Bryant & Nunes, 2002; Miller & Vernon, 1997; Rittle-Johnson, Siegler & Alibali, 2001; Thornton, 1999; Siegler, 1996).

Developmental factors also play an important role in arithmetic ability. Kail and Hall (1999) implied that additive reasoning is more evident in children from five years old when they demonstrate utilisation of many various addition strategies and do not rely purely on counting, in contrast to children younger than five. Huttenlocher, Jordan and Levine (1994) suggested that children as young as five years of age can transfer the symbolic meaning of numbers onto physical objects and that children’s understanding of numbers is highly analogous to the physical world.

Anuola, Leskinen, Lerkkanen and Nurmi (2004) suggest that arithmetic ability consists of many cognitive components such as basic knowledge of numbers, memory for arithmetic facts, understanding of mathematical concepts and the ability to follow procedures. The development of these skills occurs in a hierarchical manner. That is basic knowledge of numbers precedes counting and counting precedes addition.
(Anuola et al., 2004). It has also been suggested that the development of arithmetic skills is a cumulative process that is characterised by high stability and widening individual differences over time, with a positive association between initial performance and the rate of learning over time (Anuola et al., 2004). This widening of individual differences in performance indicates a need to identify factors that give rise to them, given the impact arithmetic skills have on self concept (Hay, Ashman, van Kraayenoord & Stewart, 1999).

Butterworth (2005) also supports the idea of a cumulative process in arithmetic skill acquisition, which primarily requires the concept of numerosity or the number of things in a set, to be clearly established before simple addition, or the union of two or more sets, can be calculated. Butterworth (2005) also adds that children initially acquire simple arithmetic skills by putting sets of numbers or objects together and counting the members of their union. The reaction time for resolving the problem decreases with age indicating developmental influences and depends on the learning history of the individual. In addition, according to Butterworth, facts that are learned earlier and practiced more will show greater accessibility.

According to Anuola et al. (2004) the level of ability to resolve arithmetic problems is positively correlated with the levels of counting ability, metacognitive knowledge and listening comprehension children display at the beginning of the preschool year. Furthermore it has been suggested the higher the level of counting ability and visual attention that children display at the beginning of schooling, the faster the rate of growth in arithmetic performance (Anuola et al., 2004). In addition, Miller and Vernon (1997) propose the rate of processing speed and the ability to monitor errors in resolving arithmetic problems increase with age suggesting developmental influences in cognitive processes.
A study conducted by White, Alexander and Daugherty (1998) indicated that analogical reasoning is another important factor in acquiring arithmetic ability in four and five year old children. Analogical reasoning in this study was described as the basic processes involved in perceiving similarities and differences among a range of objects, people or events. The results of the study indicated a significant association between cognitive processes involved in analogical reasoning and those of arithmetic learning in young children. The researchers also suggested that children who do not display automatic analogical reasoning can be trained to reason analogically.

Analogical reasoning as a predictor of arithmetic skill acquisition has also been supported in a study conducted by Canobi, Reeve and Pattison (1998) which investigated the role of conceptual understanding in children’s addition problem solving. The study involved consecutive addition problems, which were grouped with an aim to reflect association principles among problems. Results of the study indicated that children’s understanding of problem relationships based on the strength of association among the addition problems and the additive composition or the structure of the problem, was related to the use of more advanced addition strategies such as retrieval and decomposition (Canobi et al., 1998). Children in this study used various strategies when adding and their levels of arithmetic proficiency were correlated with the type of strategy they used, with more proficient children utilising retrieval more often than less proficient children.

*The Role of Strategy Choice in the Arithmetic Ability of Addition*

The type of instruction and a teacher’s ability to teach a skill to students can have a big impact on children’s ability to solve arithmetic problems (Fuchs, Fuchs, Prentice, Burch, Hamlett, Owen, Hosp & Jancek, 2003; Fuchs, Fuchs, Prentice, Hamlett, Finelli & Courey, 2004; Wright, 2002). By understanding the various
strategies used by children, teachers could monitor children’s arithmetic ability and progress. In simple addition problems, research indicates children utilise multiple strategies (Geary & Burlingham-Dubree, 1989; Siegler, 1987; 1996; 1998; Svenson, 1975). For instance, experiments have indicated that when solving simple addition problems with addends ranging from 0 to 9, children choose whether to state answers they have remembered or generate an answer by counting (Janssen, De Boeck, Viaene, & Vallaey, 1999; Siegler, 1998). Currently, the most common way of assessing children’s utilisation of various strategies has been to ask the child how he/she arrived at the result of an addition problem. It has been suggested, however, that children are not always consciously aware of strategies they use and sometimes cannot explain which strategy they utilised when solving arithmetic problems (Siegler & Stern, 1998). This indicates a difficulty in accurate measurement of strategies children use when solving addition problems.

One of the most utilised strategies when solving addition problems is a counting all strategy which is predominant in the early stages of arithmetic problem solving (Butterworth, Zorzi, Girelli, & Jonckheere, 2001; Siegler, 1998). Groen and Parkman (1972) in their study on simple addition in primary school children suggest that children can use one of five counting models when adding two numbers. It has also been suggested that addition is initially introduced as counting and has a close relationship to cognitive processes utilised in counting (Groen & Parkman, 1972).

The basic counting model describes children using their fingers to physically represent the addends of the problem and then counting their fingers to reach the answer as a sum (Svenson, 1975). Children fall back on this strategy when they cannot easily retrieve the answer from memory (Svenson, 1975). Groen and Parkman
(1972) also suggest that adults usually use memory retrieval when adding but occasionally revert back to the counting process used by children.

Huttenlocher, Jordan and Levine (1994) indicate that cognitive development in children leads to utilisation of more complex and broader arithmetic processes. As demonstrated in a study reported by Goldman, Mertz and Pellegrino (1989), extended practice in addition has an effect on a selection of strategies in children. It has been observed that third and fourth grade students become more efficient in counting strategies and use more direct retrieval after intensive practice over a period of three months (Goldman et al., 1989). These results are supportive of general cognitive skill acquisition theories which imply extended practice leads to more rapid and accurate execution of a task requiring little conscious attention (Anderson, 1982). Thus children are likely to utilise many various strategies depending on their level of practice in arithmetic skill (Siegler, 1987).

Siegler (1998) also indicates that in addition to the level of proficiency, there is a high positive correlation between frequency of use of individual strategies for each problem, and the structural features of the problem such as the size of solution, the size of its larger addend, its smaller addend and so on. It has been suggested that children's strategies can be classified into 5 to 10 strategies with the three best documented being the min strategy, retrieval and the counting all strategy (Siegler, 1987). Siegler (1998) suggests children move from a simple counting all strategy onto more sophisticated strategies, such as counting from the larger addend (min strategy), decomposing a relatively hard problem into two easier ones, and retrieval.

Primary school children starting to acquire arithmetic skills are more likely to use retrieval for problems where the sum of addends is small, decomposition is predominantly used when one of the addends is larger than one, and the min strategy
Arithmetic Acquisition 9

is more likely to be utilised when the smaller addend is very small (Siegler, 1998). Siegler also suggests that the retrieval strategy is the fastest to execute and all other strategies serve as back up strategies. Children only use these strategies if they do not have enough knowledge of the task to utilise retrieval (Siegler, 1998).

In Siegler’s (1987) study which investigated the utilisation of different strategies in addition problems, participants included three groups of primary school children: 22 preschoolers, 28 first grade children and 18 second grade children. They were presented with 45 addition problems that varied in complexity in such a way as to influence the speed, frequency and accuracy of each strategy. The problems were presented to each child over 5 school days. Children were asked how they arrived at their answers to the problems and two raters agreed on 94% of their classifications on strategies used.

Children’s reports indicated use of five approaches: retrieval, the min strategy, counting all, decomposition and guessing. The two most commonly used strategies were retrieval and the min strategy, with 68% of children reporting use of these strategies. The majority of preschoolers also reported using counting all and guessing, and the majority of first and second graders reported using decomposition as well as other strategies. The results indicated that the min strategy was most used on problems that had larger size solutions, and the counting all strategy was used most often on problems with small differences between addends (Siegler, 1987). Guessing was utilised most often on problems with large sums and retrieval and counting all were most used on problems with small sums (Siegler, 1987).

Siegler (1987) indicates that speed and accuracy influence each strategy’s conditions of use, with fast strategies being chosen when they can generate accurate performance, and slower strategies being employed when they can generate accurate
performance and fast ones cannot. Furthermore Siegler (1987) suggests that the speed and accuracy with which children execute each addition strategy increase with age and experience.

Geary and Burlingham-Dubree (1989) conducted an external validity study of the strategy choice model for addition as proposed by Siegler (1987). Forty-two preschool and kindergarten children were presented with 25 simple addition problems. Strategies and reaction times used in problem solving were classified in accordance with the strategy choice model. During the testing period, the strategy used to solve each problem was recorded by the experimenter. Each of the strategies was classified into one of the following categories: counting all, using fingers, verbal counting or no visible strategy.

The results of the Geary and Burlingham-Dubree (1989) study supported Siegler’s (1987) findings in that the reaction time for the retrieval strategy was significantly faster than the mean solution time for the counting fingers strategy. This study also supported Siegler’s findings that with increasing probability of correct retrieval, the probability that children would use other strategies decreased. The results also indicated the retrieval strategy was the most commonly used strategy, with other strategies used when retrieval was not possible due to the difficulty of the problem and the likelihood of inaccuracy. Thus both the Geary and Burlingham-Dubree and Siegler studies demonstrate that children utilise many various strategies when adding two numbers.

Siegler (1998) integrated the utilisation of various strategies in a single conceptual framework better known as the distribution of associations model. This model implies that strategy choice is governed by the distribution of associations between an addition problem and all potential answers to that problem. The strategy
selected is a function of the associative strength between the problem and its correct answer (Siegler, 1998). According to this model, the child sets two parameters: a confidence criterion and a search length time which together indicate the maximum number of retrieval attempts a child will make before resorting to an alternative strategy. Retrieval is first attempted, and if it fails to produce a satisfactory solution, the child resorts to one of the more elaborative strategies such as counting (Siegler, 1998).

In addition to many strategies children use when adding numbers, Siegler (1988) identified three groups of children according to their strategy choice style: “good” students, “not-so-good” students and “perfectionists”. Siegler (1988) suggests that “good” students and “perfectionists” do not differ in the number of correct answers as assessed by traditional achievement measurements, but differ in strategies they utilise when solving problems. The “perfectionists” use the retrieval strategy less often than the “good” students, but when they do, it is almost always the correct answer (Siegler, 1988).

According to Siegler (1988), “perfectionists” use counting strategies more than “good” students in order to ensure the correct answer, while “good” students use retrieval more often and make more mistakes. The “not-so-good” students also employ the retrieval strategy but make more mistakes than the “good” or the “perfectionists” groups of students (Siegler, 1998). Therefore it can be suggested that the individual differences in the approach to making errors when solving arithmetic problems also contributes to the selection of strategy used.

In sum, children develop and utilise many strategies and the utilisation of their strategies changes, starting from counting and progressing to more sophisticated strategies such as retrieval. As they gain skills and develop an understanding of
arithmetic, they develop memories of past solutions (Siegler, 1998). It can be suggested therefore, that skills such as the ability to retrieve past solutions, used in adding could assist with other arithmetic problems such as multiplication. The utilisation of retrieval could therefore be correlated with the ability to solve more complex arithmetic problems such as multiplication.

The Role of Strategy Choice in Ability to Solve Multiplication Problems

Children's early multiplication strategies develop from and relate closely to their early addition and subtraction strategies (Wright, 2002). Research on multiplication skills indicates that, just like in addition, children utilise many various strategies when presented with a multiplication problem (Siegler, 1996).

Developmental research on cognitive skill acquisition, in relation to the ability to solve multiplication problems, suggests a transition from a basic counting based performance in younger children to retrieval in older children (Koshmider & Ashcraft, 1991).

It has been suggested that children in the first year of multiplication instruction use strategies other than retrieval three times as often for difficult problems as for easy ones (Siegler, 1996). By the second and the third year of multiplication instruction, retrieval becomes a more predominant strategy of choice when children are presented with easy or more complex multiplication problems (Koshmider & Ashcraft, 1991; Siegler, 1996). Siegler (1988) also suggests that, according to his distribution of associations model, the strength of connection between the problem and the solution also influences children's multiplication processes where the stronger associations are more likely to produce the correct solution.

The distribution of associations model states that there are associations present between each problem and possible answers, both correct and incorrect (Siegler,
The process that operates in this network involves three sequential phases, where any one can produce an answer and terminate the process; retrieval of an answer, elaboration of the representation and application of an algorithm (Siegler, 1988). Furthermore, Siegler (1996) indicates that the use of back up strategies, such as repeated addition, is highly correlated with the percentage of errors occurring in a particular problem. It has also been implied that the level of complexity of the multiplication problem influences the selection of the strategy employed when solving the problem, so more complex problems are likely to be solved with utilisation of repeated addition and less complex problems by using retrieval (Siegler, 1996).

Lemaire and Siegler (1996) provided further evidence of utilisation of various strategies by primary school children when solving multiplication problems. This study, which involved second grade students, investigated the utilisation of various strategies three times within a school year. The results of the study indicated improvements in speed and accuracy, introduction of new strategies, increasing use of the most efficient strategy, more efficient execution of strategies and more adaptive choice among strategies by the third measurement (Lemaire & Siegler, 1996). Thus the development of cognitive skills and practice influence the speed, accuracy and effectiveness of the ability to solve multiplication problems.

Lemaire and Siegler (1996) suggested that children used various strategies at all three observation points in their study, with the retrieval strategy being the most commonly used, and repeated addition being most commonly employed for the most difficult problems. Koshmider and Ashcraft (1991) support these findings on strategy selection, and suggest that arithmetic processing in simple multiplication is partially automatic, implying retrieval utilises the associative knowledge structures in long term memory. A study by Lemaire, Barret, Fayol and Abdi (1994) that investigated
the strength of arithmetic associations in the long term memory of primary school
children suggested that children tend to automatically retrieve solutions from
associative networks in a similar way to adults.

Mabbott and Bisanz (2003) conducted a study that investigated developmental
changes and individual differences in 9 and 11 year old children by examining
multiple measures of computational skill, conceptual knowledge of arithmetic facts
and working memory of participants. Computational skills were defined as the
accuracy, the speed and the strategy used to solve the problems. Conceptual
knowledge referred to understanding of the underlying principles and the
interrelations among numbers, and was assessed with a series of problems used to
examine understanding of underlying principles and ability to apply previously
learned knowledge to novel situations. Working memory capacity was examined with
the WISC-III the backward digit span subtest.

Mabbott and Bisanz (2003) suggested that children’s performance on
measures of multiplication and memory generally improve as a function of age and
schooling. Additionally, it was implied that children, when solving multiplication
problems, do not select strategies and procedures randomly, but rather repeated
addition was most commonly used with smaller operands. It was also suggested that
specific problem characteristics such as the size of operands and their position in the
problem, influence the use of retrieval in younger children and are related to the speed
with which answers were retrieved (Butterworth, Zorzi, Girelli, Jonckheere, 2001;
Campbell, 1987; Lemaire, Barret, Fayol & Abdi, 1994; Mabbott & Bisanz, 2003).

In relation to the role of working memory in multiplication skills, Mabbott and
Bisanz (2003) demonstrated a low correlation between working memory capacity and
computational measures of multiplication. Mabbott and Bisanz explained these
findings by suggesting that the tested children had sound memory skills but disliked arithmetic and consequently did not spend time practicing mathematics. Therefore, it could be suggested that even though working memory capacity seems to have an important role in the acquisition of arithmetic skill, the particular influence and relevance in acquisition of these skills requires further investigation.

*Working Memory Capacity and Arithmetic Ability*

Individual differences in working memory processing speed and capacity have been identified as playing an important role in the ability to solve reasoning and arithmetic problems, as well as contribute to an improvement in fluid intelligence (Cooney, & Swanson, 1990; Daneman & Green, 1986; Fry & Hale, 1996; Kemps, De Rammelaere & Desmet, 2000; Schneider, 2002). Steep rises in memory development have been observed in children from 6 to 11 years of age at which time children create a meaning, where prior to this stage they are more likely to rely on rote learning (Schneider, 2002). This might contribute to the increased reliance on retrieval as an arithmetic strategy later in childhood (Bull & Johnston, 1997; Gathercole, 1998; Schneider, 2002).

Baddeley and Hitch (2000) have developed a model of working memory that accounts for age differences in memory span, primarily in terms of processing speed. The working memory can be defined as a subsystem of the short term memory which consists of three components: the central executive, the phonological loop, and the visuospatial sketchpad (Baddeley, 1992). The central executive system is an attentional controlling system of the two other so called “slave systems” that are specialised for the processing and manipulation of limited amounts of information within highly specific domains (Baddeley, 1992; Gathercole, 1988). Functions of the central executive system include the coordination of the flow of information through
working memory, the retrieval of information from more permanent long-term memory stores, and the application of retrieval strategies and mental arithmetic (Baddeley & Hitch, 2000; Gathercole, 1988; Gathercole & Baddeley, 1989; Kemps, De Rammelaere & Desmet, 2000).

Research conducted on the working memory of college age adults suggests that processing and storage capacity varied among participants and was influenced by the characteristics of the task being performed such as the complexity of the problem (Daneman & Green, 1986). The capacity theory of working memory by Just and Carpenter (1992) suggests that working memory capacity is mediated by cortical activation and that the total amount of activation available in working memory varies among individuals.

These individual differences in working memory capacity could account for the utilisation of different strategies when solving simple arithmetic problems. Children who have larger working memory capacity, according to the working memory capacity theory, could hold more information in their working memory when solving arithmetic problems which could assist in retrieving the solution to arithmetic problems (Just & Carpenter, 1992). Furthermore it has been implied that the amount of knowledge in a particular domain can impact on the domain related memory tasks and can improve efficiency of basic processes, acquisition and execution of strategies (Schneider, 2002; Swanson, 2004). Therefore children who have a larger system of knowledge relating to numeracy and arithmetic problems could have an advantage and be more efficient in their ability to solve arithmetic problems such as multiplication.

Research conducted by Gathercole, Pickering, Knight and Stegmann (2004) that investigated the working memory skills and educational attainment of children
between 7 and 14 years of age indicated that there was a high positive correlation between children's working memory abilities and their performance on national curriculum assessments. For instance, it was found that children who performed poorly on The Working Memory Test Battery for Children were failing to achieve good results in English and mathematics (Gathercole et al.). These results suggest the relevance of working memory capacity in the ability to solve arithmetic problems.

A study by Mclean and Hitch (1999) also suggested the relevance of working memory capacity in the ability to acquire arithmetic skills and emphasised the relevance of the specific subsystems of working memory in 9 year old children. A battery of 10 tasks was used to assess the different aspects of working memory and it was implied that children with poor arithmetic ability had a phonological loop within a normal range, but indicated some deficits in spatial working memory as well as in tasks designed to assess the ability for holding and manipulating information from long term memory (Mclean & Hitch, 1999). Therefore, researchers suggested that limitations in spatial and executive aspects of working memory were associated with poor performance on arithmetic tasks (Hamann & Ashcraft, 1985; Mclean & Hitch, 1999).

In contrast to previous research, a study by Temple and Sherwood (2002) suggests there is no evidence that individual differences in working memory capacity are related to arithmetical skill acquisition. The study by Temple and Sherwood (2002) examined representation and retrieval facts in 10 children who displayed an arithmetic disorder and 16 children without arithmetic disorders by measuring verbal IQ, retrieval of arithmetic facts and number processing skills such as reading and writing number words, repetition of numbers, and transcoding numbers into words and words into numbers.
This study also examined working memory capacity by measuring various aspects of memory (i.e., for digit span forward and backward, Corsi span, word span and speed of retrieval). Results of this study indicated no significant differences between the groups of children with and without arithmetic disorders on measures of working memory span, including digit span backward or forward, and no significant correlation between scores on the number of correct multiplication facts and any of the span measures (Temple & Sherwood, 2002). The results of this study suggest, in contrast to the study by Mclean and Hitch (1999), that there was no evidence that children who display poorer arithmetic skills have more limited working memory capacity than those who are more proficient in arithmetic skill.

A single case study by Butterworth, Cipolotti and Warrington (1996) supported the findings by Temple and Sherwood (2002) in that it did not find any evidence to support the association between working memory capacity and the ability to retrieve arithmetic facts. This study measured the ability of a single participant with short term memory impairment, to retrieve arithmetic information in a range of tests including oral calculation, written calculation, manipulation of numbers including decimals and fractions, approximation, magnitude and ratio. Working memory tests included digit and letter span tests, and short term forgetting.

The findings of this study implied that even though the participant displayed a significant impairment on the range of working memory tasks, his performance on a range of arithmetic facts was within a normal range (Butterworth et al., 1996). A study by Bull and Johnston (1997) also supported this conclusion and suggested there was no evidence for the prediction of more proficient arithmetic ability resulting from a larger working memory capacity. In their findings they suggest when measures of working memory, processing speed and retrieval of information were taken for 7 year
old children, and reading ability was controlled for, arithmetic ability was best predicted by processing speed, and working memory capacity accounted for no further unique variance (Bull & Johnston, 1997). Contradictory evidence in relation to the relevance of working memory capacity differences in the ability to retrieve arithmetic facts and acquisition of arithmetic skill indicates a need for further investigation into the role of working memory in this area of cognitive skill. As implied by Bull and Johnston (1997), arithmetic difficulties could be linked to the speed of processing and the automatisation of basic arithmetic fact deficits. Research should be conducted with an aim to clarify some of these issues rather than to rely on an explanation in terms of working memory deficits alone.

Conclusion

Although children acquire some form of arithmetic skill early in childhood, many factors such as individual differences, developmental factors, as well as social and economic factors influence the ability to acquire arithmetic facts. The ability to acquire these skills can have a profound impact on the development of self concept and can transfer onto other areas of academic achievement. These findings highlight the importance of research in these areas in order to determine crucial factors that underlie the acquisition of arithmetic skills.

It has been suggested that children utilise many various skills and strategies when solving simple arithmetic problems such as addition as well as analogical reasoning. Some of the strategies children utilise include guessing, counting all, min strategy, decomposition, retrieval and many more. Researchers have also suggested that the acquisition of arithmetic skills is conducted on a cumulative basis, therefore children will acquire numeracy skills such as counting before more complex skills such as addition. Based on the notion of cumulative acquisition of arithmetic skills it
can be suggested that strategies children use when adding will also progress from simple strategies such as counting to more complex strategies such as decomposition and retrieval.

The utilisation of various strategies has been described in a single conceptual framework known as the distribution of associations model (Siegler, 1988). This model implies that strategy choice is governed by the distribution of associations between an addition problem and all potential answers to that problem. The probability of retrieving a correct answer, according to this model, will be dependent on the strength of the association between the problem and the solution (Siegler, 1988).

The ability to solve more complex arithmetic problems such as multiplication has also been linked to utilisation of various strategies such as repetition adding and retrieval. Mental multiplication processing has also been described in terms of associative distribution network associations between problems and solutions in multiplication, which will determine whether the correct answer is likely to be retrieved (Siegler, 1998). Additionally, children select from a variety of strategies when solving a problem depending on individual characteristics and the complexity of the multiplication problem. Children’s performance on measures of multiplication ability generally improve as a function of age and schooling.

It has also been suggested that individual differences in working memory capacity could account for the employment of different strategies when solving arithmetic problems. Therefore children who have larger working memory capacity, according to working memory capacity theory by Baddeley (1992), could hold more information in their working memory when solving arithmetic problems which could assist in retrieving the solution to arithmetic problems (Just & Carpenter, 1992). There
is some evidence to suggest that working memory capacity and educational attainment are positively correlated (Gathercole et al. Mclean & Hitch, 1999). However, other that investigated the association between children’s and adults’ arithmetic abilities and the working memory capacity suggest there is no correlation between these two variables and that some other factors such as the processing speed need to be further investigated (Butterworth, Cipolotti, & Warrington, 1996; Temple & Sherwood, 2002).

Given the magnitude of the factors involved in acquisition of any cognitive skill, the previously mentioned studies have given a small insight into the many processes involved when acquiring arithmetic skills. Further research is needed to answer whether there is a relationship between strategies used and the ability to solve arithmetic problems with various complexity levels, such as addition and multiplication. Another important question posed by previously mentioned research, given contradictory results thus far, is the role of working memory capacity in ability to solve arithmetic problems. Further research to investigate these questions is strongly recommended.
References


The Role of Strategy Choice and Working Memory Capacity in Arithmetic Acquisition in Third Grade Primary School Children

Research Project

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Abstract

The Role of Strategy Choice and Working Memory Capacity in Arithmetic Acquisition in Third Grade Primary School Children

This project was focused on how children come to understand basic arithmetic rules and acquire strategies and principles that help them to resolve arithmetic problems. Research conducted by Siegler (1987) indicated that children use multiple strategies such as counting and retrieval from memory. Other research also indicated that a larger working memory capacity is more likely to result in better academic achievement in areas such as language and mathematics (Gathercole, Pickering, Knight & Stegmann, 2004). In order to test previous results and expand knowledge of arithmetic skills this research investigated strategies used by 52 third grade children, their working memory capacity in the domains of sentences, digit span forward and object search, and their ability to solve multiplication problems. Analysis indicated the children who utilised retrieval strategy when adding were able to solve more multiplication problems than children who utilised other strategies; counting all and min strategy. The three domains of working memory were also positively correlated with the number of correctly solved addition and multiplication problems. The strategy selected when solving the most complex addition problem was a significant predictor of the ability to correctly solve multiplication problems. Implications for future research and the implementation of these findings aiming at enhancing teaching of arithmetic in primary school were discussed.

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Submitted: October, 2005
Introduction

Researchers in cognitive psychology and educational psychology investigate how people acquire basic numeracy and basic concepts of mathematics, and the cognitive processes that underlie this acquisition (Pintrich, 1994). As reported by Hay, Ashman, van Kraayenoord and Stewart (1999), low achievement in mathematical skill is highly correlated with reduced self-concept and has an impact on other academic fields and academic self-concept in children of primary school age. Given the relevance of mathematical skills in modern society, this study was designed to investigate the skills and strategies that contribute to the ability to solve mathematical problems, in particular arithmetic problems.

Developmental Influences

Most psychologists in the areas of educational and cognitive psychology would agree that many environmental factors, including social and economic factors can contribute to individual differences in the ability to understand arithmetic principles and can shape children’s performance (Browne-Miller, 1994; Bryant & Nunes, 2002; Miller & Vernon, 1997; Rittle-Johnson, Siegler & Alibali, 2001; Siegler, 1996; Thornton, 1999). Additionally, some psychologists argue that all children have innate arithmetic skills and display them as early as two months of age (Butterworth, 2005; Gelman & Meck, 1983). Regardless of whether these skills are innate or acquired, most children display them from an early age. Huttenlocher, Jordan and Levine (1994) suggested in their study on mathematical skill acquisition that children as young as five years of age can transfer the symbolic meaning of numbers onto physical objects and that children’s understanding of numbers is highly analogous to their understanding of the physical world.
Anuola, Leskinen, Lerkkanen and Nurmi (2004) suggest that the development of arithmetic skills occurs in a hierarchical manner. That is, basic knowledge of numbers precedes counting and counting precedes addition. They also imply that the development of arithmetic skills is a cumulative process characterised by high stability and widening individual differences over time. These differences have a positive association between initial performance and the rate of learning over time (Anuola et al., 2004). Given the impact arithmetic skills have on self concept and other academic achievement, the widening of individual differences in arithmetic performance indicates a need to identify their causal factors (Hay et al., 1999).

Butterworth (2005) supports the idea of cumulative acquisition of arithmetic skill, and suggests that children initially acquire simple arithmetic skills by putting sets of numbers or objects together and counting the members of their union, with the reaction time for resolving the problem decreasing with age. Additionally, according to Butterworth, facts that are learned earlier and practiced more show greater accessibility. Miller and Vernon (1997) also support the idea of developmental influences in cognitive processes indicating that the rate of processing speed and the ability to monitor errors in resolving arithmetic problems increases with age.

Another important factor in whether or not arithmetic ability is acquired in preschool age children is analogical reasoning. This refers to the ability to perceive similarities and differences among a range of objects, people or events (Canobi, Reeve & Pattison, 1998; White, Alexander & Daugherty, 1998). A study on analogical reasoning in arithmetic skills in children by Canobi, Reeve and Pattison (1998) indicated children’s understanding of an addition problem is based on the strength of association between the addition problem and the solution. The structure
of the problem and its complexity was related to the use of more advanced strategies when solving the problem.

*Strategy Choice in Arithmetic Ability*

In simple addition problems, research indicates that children utilise multiple strategies (Geary & Burlingham-Dubree, 1989; Siegler, 1987; 1988; 1996; 1998; Siegler & Stern, 1998; Svenson, 1975). Although children are not always aware of the strategy they use when solving problems (Siegler & Stern, 1998), the most common way of assessing children’s utilisation of the various strategies has been to ask the child how s/he arrived at the solution. The various strategies that have been observed include counting all, min strategy and retrieval strategy.

The most predominant strategy in the early stages of arithmetic problem solving is a “counting all” strategy where children hold up fingers to physically represent the addends of the problem and then count all the raised fingers to generate the sum (Butterworth, Zorzi, Girelli, & Jonckheere, 2001; Siegler, 1998; Svenson, 1975). Children and adults are most likely to rely on this strategy when they cannot easily retrieve the answer from memory (Groen & Parkman, 1972; Svenson, 1975). As children develop cognitively and become more practiced and efficient in solving problems, they move away from this strategy onto more complex arithmetic processes (Goldman, Mertz & Pellegrino, 1989).

Some of the more advanced strategies include decomposition, min strategy and retrieval (Siegler, 1989). Decomposition involves decomposing numbers into smaller components and adding them in groups of smaller addends (e.g., 5+7=5+5+2). The min strategy involves counting on from the larger addend. The most advanced of all, according to Siegler (1989), is the retrieval strategy which involves retrieving the solution to a problem from long term memory. Research
indicates that primary school children starting to acquire arithmetic skills are more likely to use retrieval for problems where the sum of addends is small (e.g., 2+3) and the min strategy is more likely to be utilised when the smaller addend is very small (e.g., 7+2) (Siegler, 1987). The strategy selected to solve more complex arithmetic problems (e.g., 8+5) where both addends are larger or equal to 5, seems to distinguish between children who are more proficient in arithmetic and others, with those who are more proficient being more likely to rely on retrieval, and less proficient children tending to rely on strategies such as counting all and min strategy (Siegler, 1987).

Experiments have indicated that when solving simple addition problems with addends ranging from 0 to 9, children decide whether to state answers they have remembered and retrieved from memory or generate an answer by counting (Janssen, De Boeck, Viaene & Vallaeys, 1999; Siegler, 1998). Children are likely to utilise various strategies depending on their level of practice (Siegler, 1987). In the transition phase, several strategies could be used and the employment of the strategy can be determined by the structural features of the problem such as the size of addends, the size of the solution, the size of the smaller addend and so on (Siegler, 1998).

Cognitive skill acquisition theories state that extended practice leads to more rapid and accurate execution of a task requiring little conscious attention (Anderson, 1982). Therefore it could be predicted than children would progress, depending on their level of proficiency in arithmetic skill, from simpler strategies such as counting, to more advanced strategies. The min strategy is regarded as a strategy which is one step more advanced than counting all, because it involves counting on from a larger addend. With increasing levels of expertise it is to be expected that children would ultimately end up relying on retrieval almost exclusively as the most advanced strategy to solve arithmetic problems.
Siegler’s (1987) proposal that children utilise various strategies to solve addition problems was also supported in a study conducted by Geary and Burlingham-Dubree (1989). In this study, which involved 42 preschool children, it was observed that retrieval was the most commonly used strategy. Geary and Burlingham-Dubree suggested that other strategies were used only when retrieval was not possible due to the difficulty of the problem and the likelihood of inaccuracy. Additionally, the reaction time for problems that had been solved by the retrieval strategy was significantly faster than for problems solved with other strategies such as the counting all strategy.

It has also been suggested that children utilise various strategies when presented with multiplication problems, just as they do for addition problems (Wright, 2002). In multiplication problems, children progress from simpler strategies such as repeated addition to more advanced strategies such as retrieval (Koshmider & Ashcraft, 1991). Siegler (1996) suggests that in the initial stages of multiplication problem solving, the level of complexity of the multiplication problem influences the selection of the strategy utilised to solve the problem. More complex problems are initially solved using repeated addition and less complex problems using retrieval, whereas in the second and third year of multiplication, retrieval becomes the predominant strategy of choice (Siegler, 1998).

In sum, children develop and utilise many strategies when solving arithmetic problems. The utilisation of these strategies is correlated with the complexity of the problem, and is influenced by individual differences in the ability to solve problems, and other environmental influences such as exposure to numbers and mathematical concepts from an early age (Goldman, Mertz & Pellegrino, 1989). As they gain skills and develop an understanding of arithmetic, children develop memories of past
solutions (Siegler, 1998). Therefore skills used in adding could assist with other arithmetic problems such as multiplication. The utilisation of retrieval in addition problems could be correlated with the ability to solve more complex arithmetic problems such as multiplication. This hypothesis was investigated in the current study. In particular, the experiment was designed to examine whether the utilisation of retrieval in simple addition is predictive of the ability to solve more complex arithmetic problems such as multiplication. In this way, the study represents an attempt to expand previously conducted research on strategy selection by linking strategies used to solve addition problems with ability to solve multiplication problems.

*The Influence of Working Memory Capacity on Arithmetic Ability*

In addition to the progression from strategies such as counting to more advanced strategies such as retrieval, it has been stated that individual differences in working memory capacity could account for the utilisation of different strategies when solving simple arithmetic problems (Schneider, 2002). That is, children with larger working memory capacities could hold more information in their working memory when solving arithmetic problems, and this would have the effect of resulting in a greater number of correct solutions. According to the working memory capacity theory of Just and Carpenter (1992), working memory capacity is mediated by cortical activation and the total amount of activation available in working memory varies among individuals. These individual differences could impact on the ability to correctly solve arithmetic problems.

Swanson (2004) and Schneider (2002) indicate that the quantity of knowledge in a particular domain can impact on domain related memory tasks by influencing the efficiency of basic processes, acquisition and execution of strategies. Thus children
who have a larger system of knowledge relating to numeracy and arithmetic problems could have an advantage and be more efficient in their ability to solve arithmetic problems. The relevance of working memory capacity to the ability to solve arithmetic problems was demonstrated in a study by Gathercole, Pickering, Knight and Stegmann (2004) in which children who performed poorly on The Working Memory Test Battery for Children were also failing to achieve good results in English and mathematics.

In contrast to the results of Gathercole et al. (2004), a study by Temple and Sherwood (2002) suggested there was no evidence that individual differences in working memory capacity are related to arithmetic skill acquisition. This study examined representation and retrieval in two groups of children, those with an arithmetic disorder and those without such disorder, on a number of arithmetic facts, number processing skills and working memory capacity. The results indicated no significant differences between the groups on measures of working memory span, including digit span backward or forward, and no significant correlation between scores for the number of correct multiplication facts and any of the working memory span measures (Temple & Sherwood, 2002). The lack of correlation between working memory capacity and arithmetic ability contradicts previously mentioned findings. This conflict indicates a need to investigate the role of the working memory capacity in the ability to solve arithmetic problems.

The purpose of this study was to investigate the ability to solve arithmetic problems such as multiplication as a function of the skills and strategies used when solving less advanced arithmetic problems such as simple addition. As previously mentioned, research indicates the development of processing skills and utilisation of more advanced skills such as retrieval when adding is likely to result in more accurate
results and shorter execution time, which might increase the likelihood of solving more advanced arithmetic problems such as multiplication. Based on these assumptions, it is hypothesised that children’s strategy selection with addition problems is correlated with their ability to solve more complex arithmetic problems. Therefore it could be expected that children who utilise simpler forms of strategies such as counting all or the min strategy when adding are less likely to be able to solve multiplication problems than children who employ more advanced strategies such as retrieval. Thus the utilisation of retrieval in addition would be correlated with the ability to solve multiplication problems.

A further goal of this study was to investigate whether individual differences in working memory capacity are correlated with the ability to solve multiplication problems. The influence on arithmetic ability of working memory as measured in several domains (language, object search and digit span) was also investigated. The specific hypotheses under test in this study were: (1) the number of correct addition problem solutions and the number of correct multiplication solutions would be positively correlated with use of advanced strategies when adding; and (2) the ability to solve multiplication problems would be positively correlated with working memory capacity in the domains of sentences, object search and digit span, with the most likely outcome being that children who are able to solve multiplication problems would have larger working memory capacities in the more domain relevant area of digit span.

Method

Participants

The participants were 52 children that were recruited from a private school in a Perth suburb. The sample consisted of 26 boys and 26 girls attending third grade.
The participants’ ages ranged from 7 years and 7 months to 8 years and 5 months, with the mean age being 8 years and 2 months. The participants were from similar middle socio-economic backgrounds and from English speaking backgrounds. Two of the participants had hearing disabilities and their results were also included in this study. All of the children participated on a voluntary basis, with written and oral consent being obtained from the school principal, staff, parents and children before testing. Participants were not remunerated for their involvement in this study.

**Design**

The study incorporated a correlational design, which measured 6 variables and investigated their relationship. These variables include the number of correct answers for 10 addition problems, the number of correct answers for 10 multiplication problems, the number of times a particular strategy was used when adding (counting, min strategy and retrieval), and the working memory capacities for sentences, digit span forward and object search.

**Materials**

The school principal and parents were given information letters about the study (Appendix A, Appendix B) and parents and guardians were given consent forms (Appendix C). Children were provided with information about the study, which was read to them prior to conducting testing (Appendix D). Materials used in this study consisted of two working sheets: one contained 10 multiplication problems (Appendix E) and the other contained 10 addition problems (Appendix F). The materials also included three subtests from the Stanford Binet Intelligence Scale (Form L-M) (4th ed). The researcher recorded the children’s responses to the multiplication problems and addition problems, as well as the strategy used on each problem, as reported by the child, and the working memory capacity subtest results on individual results.
sheets (Appendix G). The three subtests included the working memory capacity subtests for sentences, digits and objects (Appendices H, I and J).

The Working Memory Capacity for Sentences. This subtest consisted of sentences ranging from simple two word sentences to more complex sentences. It included 42 sentences of various complexities (Example: High clouds appeared on the horizon.). Sentences were presented in a standard sequence, with each successive sentence containing more words than the previous sentence. The sentences were read out loud by the researcher one at a time and the child was asked to repeat each sentence immediately after hearing the researcher read it. The sequence number of the last correctly remembered sentence item was recorded as the working memory capacity for sentences.

The Working Memory Capacity for Digits. This subtest consisted of strings of numbers and only the Digit Forward component of the subtest was included in this study. The component contained 14 series of digits, 3 to 9 digits in length (Example: 3-9-5). The strings of digits were presented in a standard order, with each successive string containing more digits than the previous string. The child was asked to repeat the numbers read out by the researcher. The number of digits in the last correctly memorised string of digits was recorded as the working memory capacity for digits.

The Working Memory Capacity for Objects. The task in this subtest included recalling pictured objects in the exact sequence in which they were presented and contained 14 items. (Example: the child is first shown a picture of a knife, followed by a picture of a dog and then shown a card containing pictures of a knife, dog, spoon, cat and house). The child was first shown a picture of an object, then shown a second, different picture and then asked to identify previously seen objects among the other
objects on a picture. The highest number of previously seen objects identified on the picture was recorded as the working memory for objects.

Procedure

Prior to commencement of this study, approval was obtained from the Edith Cowan University Faculty of Community Services, Education and Social Sciences Ethics Committee. After receiving approval from the school principal and parents, the researcher read the consent form to each child and briefly explained the testing procedure. Participants were tested individually, in a quiet, separate room, away from other class participants. The testing was conducted in the morning and children were called out of the classroom individually in alphabetical order. Each child was informed that participation was voluntary and that s/he could withdraw from the testing at any time. They were also informed that there were no penalties for not solving a problem or if they produced the wrong answer.

Each testing session lasted for approximately 15 minutes. The child was first presented with 10 multiplication problems with multiplicands from 0-9, one at a time (Appendix A). The results were recorded on an individual results sheet. This was followed by 10 addition problems (Appendix B), with addends from 0 to 9. The child was not provided with feedback on whether their responses to the problems were correct. After providing a solution to each addition problem, each child was asked: “How did you figure out the answer to that problem?” The child’s description of the strategy used and the answer obtained were recorded on the result sheet.

After completion of the arithmetic problems, the child’s working memory capacity was measured using the three working memory subtests (sentences, digit span forward, object search) of the Stanford Binet Intelligence Scale (4th ed) for children.
Results

Data Screening and Accuracy

The data were analysed and screened using SPSS for Windows. There were no errors in data entry and no cases of missing data. The normality tests indicated that the scores on the working memory measures were normally distributed. There were also no significant departures from normality on measures of addition and multiplication ability.

The mean accuracy of the solutions provided to the addition and multiplication problems is presented in Table 1. The children were clearly more likely to solve the addition problems correctly than the multiplication problems.

Table 1

<table>
<thead>
<tr>
<th></th>
<th>Addition Problems</th>
<th>Multiplication Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Addition Problems</td>
<td>8.73</td>
<td>1.61</td>
</tr>
<tr>
<td>Multiplication</td>
<td>5.87</td>
<td>2.73</td>
</tr>
</tbody>
</table>

Strategies Selected for 10 Addition problems

The mean frequency with which each of the strategies was used to solve an addition problem is presented in Table 2. This data shows that the retrieval strategy was the most commonly used strategy. The counting all strategy was the least commonly used. The strategies reported by the children were only recorded if the answer to the addition problems was correctly answered. The strategies reported for incorrect answers were not recorded.
Table 2

**Frequency of Strategy Usage for the Addition Problems**

<table>
<thead>
<tr>
<th>Times selected</th>
<th>Counting All Strategy</th>
<th>Min Strategy</th>
<th>Retrieval Strategy</th>
<th>Other Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( M )</td>
<td>2.79</td>
<td>5.30</td>
<td>.17</td>
</tr>
<tr>
<td></td>
<td>( SD )</td>
<td>2.05</td>
<td>2.63</td>
<td>.38</td>
</tr>
</tbody>
</table>

Chi Squared Test for Goodness of Fit Analysis

Chi Squared analysis was conducted to investigate the relationship between the strategy selected when solving addition problems and the ability to solve multiplication problems. The strategy selected for this analysis was the most commonly used strategy when adding, as reported by the child. All of the assumptions of the Chi Squared test were satisfied by the data. Table 3 shows the observed frequencies with which strategies were selected in relation to whether a child solved 0-50% of the addition problems correctly or 50-100% of the addition problems correctly.

Table 3

**Frequency of Strategy Selection in 0-50% Correct Addition Solutions and 50-100% Correct Addition Solutions**

<table>
<thead>
<tr>
<th></th>
<th>Counting</th>
<th>Min</th>
<th>Retrieval</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-50% addition correct</td>
<td>6</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>50-100% addition correct</td>
<td>0</td>
<td>1</td>
<td>35</td>
</tr>
</tbody>
</table>

The results of the Chi Squared test indicated a significant result, \( \chi^2 (2) = 51.99, p < .05 \), indicating that selection strategy is related to the ability to correctly solve
addition problems. In particular, those children who used the retrieval strategy most often were more likely to solve over 50% of the addition problems correctly.

Bivariate Correlation Analysis

Bivariate Correlation analysis was performed to investigate the relationship between the strategy selected, the working memory capacity measures and the ability to solve multiplication problems. Six measures were examined in this analysis: the number of correct answers for the 10 addition problems, the number of correct answers for the 10 multiplication problems, the strategy selected when solving the most complex addition problem, and the scores on the working memory tests. Following Siegler (1989), the most complex problem was defined as the problem with both addends being equal or larger than 5 (i.e., 8+5). The strategy utilised when solving this problem was coded as “1” for the simplest strategy which was counting all, “2” for the min strategy, and “3” for the most advanced strategy which was retrieval. The results of this analysis are presented in Table 4.

Table 4

Correlation Coefficients for the Six Measures

<table>
<thead>
<tr>
<th>Measures</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants (n = 52)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Multiplication</td>
<td>-</td>
<td>.607**</td>
<td>.427**</td>
<td>.278*</td>
<td>.302*</td>
<td>.437**</td>
</tr>
<tr>
<td>2. Addition</td>
<td>-</td>
<td>.555**</td>
<td>.387**</td>
<td>.385**</td>
<td>.419**</td>
<td></td>
</tr>
<tr>
<td>3. Strategy</td>
<td>-</td>
<td>.363**</td>
<td>.494**</td>
<td>.333*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. WMC sentences</td>
<td>-</td>
<td>.529**</td>
<td>.569**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. WMC digits</td>
<td>-</td>
<td>.403**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. WMC objects</td>
<td>-</td>
<td></td>
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</tbody>
</table>

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
As shown in Table 5, there was a significant positive correlation between the number of correct multiplication problem solutions and the number of correct addition problem solutions, as well as a significant positive correlation between multiplication performance and the strategy used to solve the complex addition problem. That is, children who used the retrieval strategy were more likely to answer correctly a higher number of multiplication problems than children using other strategies.

There was also a significant positive correlation between the number of correct multiplication problems and all of the working memory capacity measures. The three working memory capacity measures were positively correlated with the ability to correctly solve addition and multiplication problems. The strategy selected when solving the complex addition problem was also positively correlated with the three working memory capacity measures.

**Multiple Regression Analysis**

In order to investigate the relationship between the ability to solve multiplication problems and the strategy used when solving the most complex addition problem, a multiple regression analysis was performed. This analysis was performed with two predictor variables, the first one being the strategy used when solving the most complex addition problem (8+5), and the second one being the working memory capacity for digit span, as previous research has identified domain relevant memory span as an important factor in arithmetic ability (Gathercole, Pickering, Knight & Stegman, 2004).

The criterion variable was the number of correct solutions for the 10 multiplication problems. The ratio of cases to predictor variables exceeded the ratio of 20 cases per predictor. Data screening indicated one outlier in the working memory capacity for digits predictor variable, with one participant recalling less than 4 digits.
This predictor variable was, however, normally distributed so it did not require transformation. An examination of Mahalanobis Distances indicated there were no multivariate outliers in the sample.

The regression equation accounted for a significant amount of variance in the number of correct solutions for the multiplication problems \(F(2, 52)=5.88, p<.05\). The two predictor variables accounted for 16.1% of the variance in multiplication performance, however the strategy selected when solving the most complex addition problem was the only significant predictor of the ability to correctly solve multiplication problems \(t = 2.49, p<.05\).

Discussion

The aim of this study was to investigate the relationship between the strategies utilised when solving simple addition problems and the ability to solve multiplication problems in primary school children. Additionally, this study investigated the role of three domains of working memory capacity, sentences, digit span forward and object search, in the ability to solve multiplication problems. It was hypothesised that the number of correct addition problem solutions and the number of correct multiplication solutions would be positively correlated with strategies used when adding. Additionally it was hypothesised that the ability to solve multiplication problems would be positively correlated with working memory capacity in domains of sentences, digit span and object search. It was anticipated that the most likely outcome would have been that children who were able to solve multiplication problems would have larger working memory capacities in the domain of digit span.

**The Relationship Between Strategy Selection and Addition Ability**

The present study results supported previous finding by Geary & Burlingham-Dubree (1989); and Siegler (1987) who reported children using many various
strategies when solving arithmetic problems. The most commonly used strategies when adding, as previously reported by aforementioned studies, included “counting all”, min strategy and retrieval. This study indicated that retrieval strategy was the most commonly used strategy being used on average 5.30 times out of 10 addition problems. This strategy was followed by the min strategy, which was used on average 2.79 times. The counting all strategy was the least commonly utilised strategy being used on average .46 times.

The utilisation of the most advanced strategy when solving addition problems indicated that most children did not find the addition problems very difficult, that most problems were age appropriate, and that the complexity level was appropriate given the level of expertise displayed by the children. The average number of correct answers for the 10 addition problems was also indicative of the children’s ability to solve these problems, with on average 8.73 addition problems out of 10 being correctly solved. In contrast to addition problems the average number of correct multiplication problems was significantly lower with 5.87 correct answers out of 10 multiplication problems, implying children were not as proficient at multiplication as they were in addition.

These findings were supportive of a previously reported study by Goldman, Mertz and Pellegrino (1989) who reported in their study that children move on from simple strategies to more advanced strategies as they become more proficient in their ability to solve arithmetic problems. In this study the proficiency in addition skill resulted in retrieval being the most commonly utilised strategy for solving simple addition problems. The findings of this study also supported Siegler’s (1987) findings that children utilise various strategies depending on their level of expertise.
Chi Squared analysis performed in this study investigated the relationship between children's ability to solve addition problems and the most commonly utilised strategy used for solving addition problems. The results of this analysis indicated a significant relationship between the strategy choice and the ability to solve addition problems. In the group of 36 children who correctly solved 50-100% of the 10 addition problems, 35 children utilised retrieval strategy when adding and one child utilised the min strategy. None of the children in this group utilised the simplest counting all strategy.

In the group of 16 children who solved 50% or less of addition problems correctly, six children utilised the counting all strategy, seven children reported using the min strategy and three children reported using retrieval. A significantly lower number utilised retrieval in this group and more children cumulatively utilised other strategies than retrieval with 13 children employing other strategies more commonly than retrieval strategy. These results support previously reported theories on strategy selection and general cognitive skill acquisition as implied by Anderson (1982), which suggest the level of expertise in a particular area leads to more rapid and accurate execution of a task. In this study, children who displayed more expertise in solving addition problems relied most commonly on retrieval strategy, which is the most advanced and also the most rapid and most accurate strategy for solving addition problems, supporting findings by Goldman, Mertz and Pellegrino (1989).

The bivariate correlation analysis also indicated a significant relationship between the strategy selection and the ability to correctly solve addition problems. The number of correct addition solutions was significantly positively correlated with the strategy selected when solving the most complex addition problem (8+5). These
results also supported the previous Chi Squared findings, the importance of the strategy selection and the ability to correctly solve addition problems.

The positive correlation between the correct addition solution and the strategy utilised implied that the children who employed the most advanced strategy, retrieval, were more likely to correctly solve addition problems. In other words, the ability to correctly solve addition problems was a function of the problem solving strategy selected. The other four measures of bivariate correlation analysis (the number of correct multiplication solutions, wmc for sentences, wmc for digit span and wmc for objects) were also significantly positively correlated.

**The Relationship Between Strategy Selection and Multiplication Ability**

The findings of the bivariate correlation analysis supported the previously stated hypothesis and results implied that the number of correct addition solutions and the number of correct multiplication solutions were positively correlated with the strategy selected when solving the most complex addition problem. These results indicated that there was a significant positive correlation between the strategy selected when adding and the child's ability to correctly solve multiplication problems. The identification of retrieval strategy as a significant measure when investigating arithmetic abilities in addition and multiplication was not previously identified as a link between the ability to add and multiply.

Additionally, the results of the multiple regression analysis also supported the relevance of strategy selection in the ability to multiply. The results of this analysis indicated that the strategy selected when solving the most complex addition problem was a significant predictor of the ability to correctly solve multiplication problems. Although previous research (Anuola et al., 2004; Goldman, Mertz & Pellegrino, 1989; Siegler, 1998) has identified the development of arithmetic skills as a cumulative
process, where children progress from simple concepts and skills onto more complex and advanced skills, the retrieval strategy as a link between the ability to add and the child’s readiness and ability to solve multiplication problems has not been previously established.

*The Relationship between Working Memory Capacity and Multiplication Ability*

The bivariate correlation analysis results supported the second hypothesis and indicated that the working memory capacity for the domains of sentences, object search and digit span were significantly positively correlated with the number of the correctly solved multiplication problems. Additionally, the tree working memory capacity measures were also positively correlated with the ability to solve addition problems. These results imply that as the children’s working memory capacity increases so does their ability to solve arithmetic problems. The findings of this study provide further support for previous research which investigated the role of the working memory capacity in arithmetic ability (Gathercole, Pickering, Knight & Stegmann, 2004; Schneider, 2002; Swanson, 2004).

*Limitations and Methodological Implications of the Present Study*

A number of methodological considerations and limitations have been identified in the present study. The present study was conducted on a sample of 52 participants, which limited the number of predictor variables that could be included in the regression analysis. It would be recommended to include a larger sample in order to include all three working memory capacity measures simultaneously (sentences, digit span, object search) as well as the strategies utilised when solving addition problems, in order to determine important predictor variables for the criterion of the multiplication ability. A larger sample size would increase the power of the analysis and allow identification of important predictors and their relationships.
Another important limitation of the present study was the lack of the inter rater in determining the strategy used by the child when solving addition problems. Identifying particular strategies utilised by children and correct identification has been identified as a potential cause for concern by Siegler & Stern (1998). Although careful examination of the children’s self reporting of the strategy has been employed in this study, the presence of another inter rater would have increased the reliability and the validity of the present study.

**Implications for Future Research**

The present study has demonstrated the retrieval strategy in addition problem solving and the working memory capacity for the domains of sentences, digit span and object search, as important factors in the ability to solve more complex arithmetic skills such as multiplication. It is imperative to consider the introduction of a screening process for strategies utilised when solving addition problems in order to determine whether the children are at the stage of arithmetic ability to be able to move onto more complex arithmetic skills such as multiplication.

As previously identified in education research, the technique known as scaffolding, among other things, proposes that learning should be regulated by the teachers cueing according to the child’s level of expertise in a specific area (Pape, Bell & Yetkin, 2003; Salonen, Vauras & Efklides, 2005; Stillman, 2001). This study and its findings support the idea of scaffolding where the child’s progress is monitored on an ongoing basis and is directed and build upon, depending on their level of expertise. The findings of this study, in relation to the relevance of the retrieval strategy in addition and multiplication problem solving, could be implemented in a way that teachers identify the strategy most employed by each child when adding, and build on the child’s current knowledge by gradually introducing
other strategies. Implementation of this nature would be in line with the educational idea of scaffolding. Furthermore, identifying that a particular child predominantly utilises the simplest arithmetic strategy when adding (counting all) could mean that the particular child is not ready for more complex forms of arithmetic such as multiplication.

Previous research has noted the ability to perform well in the educational area of mathematics has an impact on a child’s self esteem and also impacts on their performance in other academic areas (Hay, Ashman, van Kraayenord & Stewart, 1999). It is imperative to identify as many factors as possible affecting mathematical ability, which would alleviate the negative impacts of arithmetic acquisition and mathematical skills. Some of these factors have been identified in this study. Catering for individual differences in skill acquisition and working memory capacity, as well as allowing children to move on from simpler skills onto more complex skills at their own pace, could be the key to making these transitions less traumatic.

Conclusion

This study provided an insight into some of the factors which influence the acquisition of arithmetic skills such as the ability to add and multiply in third grade children. The focus of the study was to identify whether the strategies utilised by children were related to their ability to add and multiply. Additionally, it was investigated whether individual differences in working memory capacity also play an important role in arithmetic ability.

The results of this study identified the retrieval strategy as being the most advanced strategy utilised when solving addition and multiplication problems. This strategy was also predictive of children’s ability to multiply. Three working memory capacity domains; sentences, digit span forward and object search were also identified
as positively correlated with children’s ability to correctly solve addition and multiplication problems. The findings of this study could be implemented in educational systems by means of a screening process to assess children’s level of arithmetic expertise by identifying their most commonly used arithmetic strategy and their working memory capacity. The outcomes of such a screening process would help to identify whether children are ready to move on from simpler arithmetic skills such as addition onto more complex skills such as multiplication. This would contribute to allowing children to progress at their own pace and to have their individual differences taken into a consideration.
References


*Cognition, 13,* 343-360.


*Journal of Educational Psychology, 81*(4), 481-496.


Appendix A

Introductory Letter to Principals

Dijana Mirkovic
196 Lakeside Drive
JOONDALUP WA 6027
Ph: 9300 0703

The Principal
_______ Primary School
_________________ WA

Dear _____________,

Re: Approval to conduct research at St Stephens Primary School

I am currently completing Bachelor of Arts (Psychology) Honours degree, at Edith Cowan University. To complete the thesis component of my course I will be investigating the acquisition of arithmetic skills in third grade primary school children under the supervision of Dr Craig Speelman. The research ethics approval has been granted by the ECU Faculty of Community Services, Education and Social Sciences Ethics Sub Committee.

The ability to solve mathematical problems is an important and integral part of everyday life. This project aims to identify factors that contribute to the acquisition of more complex arithmetic skills such as multiplication. It will investigate various strategies utilised when adding, and determine whether children that use particular strategies are more likely to successfully solve multiplication problems. In addition, it will investigate whether a larger working memory capacity in a particular domain such as numeracy contributes to the ability to solve arithmetic problems. It is envisaged that the information gathered will contribute to understanding arithmetic acquisition in children and could provide some guidance toward effective teaching techniques in mathematics.

Children will be tested individually. Testing will comprise of three parts. In the first part children will be presented with 10 addition and 10 multiplication problems to solve. In the second part children will be asked to describe how they solved each problem. The last part of the tests comprises of working memory capacity tests in the domains of numeracy, language and object memory. It is estimated that all three parts of the test combined should take about 15 minutes per child. I will supervise all tests in a separate room to, or an area outside, the classroom.

I will hold all information in strict confidence and once the data is converted to electronic form it will be coded and student names will be deleted from the primary records. In the final report the data will be provided in group form only.
Appendix A (continued)

Children's participation in the project is voluntary and they will be free to withdraw at any stage during the experiment. In order for children to participate it will be necessary to obtain written permission from each child's parent. I have enclosed a copy of my research proposal, which provides more detailed information. If you have any questions concerning this project please contact myself on 9300 0703 or my supervisor Dr Craig Speelman at the School of Psychology, Edith Cowan University on 6304 5552. If you would like to speak to an independent person about this project, please contact Ms Julie Ann Pooley, the fourth year and honours coordinator on 6304 5591.

At the completion of the study, a copy of the final results will be available on request.

I hope you and your students are interested in participating in this project and I look forward to hearing from you in the near future.

Yours Faithfully,

Dijana Mirkovic
Dear Parents/Guardians

I am currently studying Bachelor of Arts (Psychology) Honours, at Edith Cowan University. To complete the thesis component of my course I will be investigating the acquisition of arithmetic skills in third grade primary school children under the supervision of Dr Craig Speelman. The research ethics approval has been granted by the ECU Faculty of Community Services, Education and Social Sciences Ethics Sub Committee.

The ability to solve mathematical problems is an important and an integral part of everyday life. This project aims to identify factors that contribute to acquisition more complex arithmetic skills such as multiplication. It will investigate various strategies utilised when adding and determine whether children that use particular strategies are more likely to successfully solve multiplication problems. In addition, it will investigate whether the larger working memory capacity in a particular domain such as numeracy contributes to ability to solve arithmetic problems. It is envisaged that the information gathered will contribute to understanding of arithmetic acquisition in children and could provide some guidance toward teaching instruction in mathematics.

Thirty children will be randomly selected from third grade and will participate in this study. Children will be tested individually. Testing will comprise of three parts. In the first part children will be presented with 10 addition and 10 multiplication problems to solve. In the second part children will be asked to describe how they solved each problem. The last part of the tests comprises of working memory capacity tests in the domains of numeracy, language and object memory. It is estimated that all three parts of the test combined should take about 15 minutes per child. I will supervise all tests in a separate room to, or an area outside, the classroom.

I will hold all information in strict confidence and once the data are converted to electronic form it will be coded and student names will be deleted form the primary records. In the final report the data will be provided in group form only.

Your child’s participation in this project is voluntary and he/she will be free to withdraw at any time during the experiment. If you consent to your child’s participation in this project please sign the attached consent form and return it to your child’s teacher as soon as possible.

If you have any questions concerning this project please contact either myself on 9300 0703 or my supervisor Dr Craig Speelman at the School of Psychology, Edith Cowan University on 6304 5552. If you would like to speak to an independent person
Appendix B (continued)

about this project, please contact Ms Julie Ann Pooley, the fourth year and honours coordinator on 6304 5591.

Yours Faithfully,
Dijana Mirkovic
Appendix C

Parent/Guardian Consent Form

Project Title: The Role of Strategy Choice and Working Memory Capacity in Arithmetic Acquisition in Third Grade Primary School Children

I ____________________________ (the parent/guardian of the participant) have read and understood the information provided with this consent form and any questions I have asked have been answered to my satisfaction.

I agree to allow my child ____________________________ (name) to participate in the tests associated with this research and I understand that I, or my child, can withdraw consent at any time.

I agree that research data gathered in this study might be published, provided my child and my child’s school are not identifiable in any way.

_________________________________________  ________________________
Parent/Guardian’s Signature                  Date
Appendix D

Child Verbal Consent

(To be read to child participants)

My name is Dijana Mirkovic and I am studying psychology at Edith Cowan University. I am doing an experiment to study how children get to solve mathematical problems and I would like you to be in my experiment.

There are three short parts to the experiment. First I will ask you to solve ten addition problems and ten multiplication problems. After this I will ask you how you solved these problems. It does not matter if you do not get the right answers. I will be the only person that will know whether you got them right or not. This will only take about ten minutes. Then I will ask you to try to remember numbers, sentences and pictures and to see whether you can repeat them for me.

Your participation in this experiment is voluntary and this means if you do not want to do the experiment you don’t have to do it. You can also stop at any time and if you choose to do so you won’t get into trouble.

Have you got any questions you would like to ask me about the experiment?

Would you like to be in the experiment?
Appendix E

Multiplication Problems

1) $3 \times 2 =$
2) $2 \times 7 =$
3) $5 \times 3 =$
4) $3 \times 6 =$
5) $8 \times 2 =$
6) $7 \times 4 =$
7) $5 \times 6 =$
8) $4 \times 9 =$
9) $2 \times 6 =$
10) $4 \times 4 =$
Appendix F

Addition Problems

1) 12 + 3 = (Min)

2) 6 + 8 = (Counting)

3) 3 + 5 = (Retrieval)

4) 4 + 2 = (Retrieval)

5) 8 + 5 = (Counting)

6) 3 + 14 = (Min)

7) 6 + 3 = (Retrieval)

8) 2 + 12 = (Min)

9) 9 + 7 = (Counting)

10) 4 + 3 = (Retrieval)
Appendix G

Name: __________________________

1) $3 \times 2 = $
2) $2 \times 7 = $
3) $5 \times 3 = $
4) $3 \times 6 = $
5) $8 \times 2 = $
6) $7 \times 4 = $
7) $5 \times 6 = $
8) $4 \times 9 = $
9) $2 \times 6 = $
10) $4 \times 4 = $

1) $12 + 3 = $
2) $6 + 8 = $
3) $3 + 5 = $
4) $4 + 2 = $
5) $8 + 5 = $
6) $3 + 14 = $
7) $6 + 3 = $
8) $2 + 12 = $
9) $9 + 7 = $
10) $4 + 3 = $

Working memory capacity:

SENTENCES:

NUMBERS:

OBJECTS:
Appendix H

Working Memory Capacity (Sentences)

Researcher: “I am going to say something. Listen carefully and try to say just as I do. Ready?”

1. See the funny clown.
2. Pat has two dogs.
3. The circus came to town.
5. Sarah likes her new bicycle.
6. The little child would not stop crying.
7. The sun is shining through my window.
8. It is time to go to sleep.
9. Ken painted a picture for his mother’s birthday.
10. Lee did not want to leave before the movie was over.
11. Going to the football game is not Dave’s idea of fun.
12. They were unable to see the aeroplane because of the smog.
13. George’s sister gave him a shirt with red and white stripes.
14. Running for a bus, the man slipped and sprained his ankle.
15. Although the ocean looks safe, it can be dangerous for swimmers.
16. Ruth fell in a puddle and got her clothes all muddy.
17. The aeroplane’s engines sputtered, then stopped, forcing an emergency landing.
18. It snowed last night, so this morning the children built a snowman.
19. Sensing defeat, the fighter’s manager threw the towel into the ring.
20. Chris chased the dog around the house but did not catch it.
21. The birds were flying and singing when Lyn got up this morning.

22. It was raining this morning, so the children carried umbrellas to school.

23. Undetected by the sleeping guard, a thief slipped into the unprotected factory.

24. The home team was ahead when a sudden storm forced postponement of the game.

25. The warm, humid weather that occurs in late summer tends to make many people feel irritable.
Appendix I

Working Memory Capacity (Numbers)

Researcher: "I am going to say some numbers. Listen carefully and try to say them just as I do. Ready?"

1. 5-7-8
2. 4-9-2
3. 2-7-6-9
4. 5-1-8-4
5. 3-1-8-5-9
6. 4-8-3-7-2
7. 2-8-3-5-9-4
8. 7-1-9-5-4-3
9. 3-5-9-6-8-4-7
10. 2-8-5-1-4-6-9
Appendix J

Working Memory Capacity (Objects)

The memory for objects test consists of common objects presented one at a time in a prescribed sequence by the researcher. The participant is required to choose the previously presented pictures in the order of presentation from a larger array of pictures.

Researcher: “I am going to show you some pictures. Then I am going to ask you to point to those pictures in the order I showed them to you. Ready?”

1. shoe, horse. Need to identify among pictures of shoe, horse, bed, car and airplane.
2. clock, elephant. Need to identify among pictures of clock, elephant, clown, bus and egg.
3. owl, Santa Clause, table. Picture contains: owl, Santa Clause, table, money, box, cup, trumpet.
4. giraffe, scissors, eye. Picture contains: giraffe, scissors, eye, girl, rock, rabbit and key.
5. deer, knife, suitcase, dress. Picture contains: deer, knife, suitcase, dress, moon, strawberry, coins and train track.
7. goat, wheel, envelope, rope, vacuum cleaner. Picture contains: goat, wheel, envelope, rope, vacuum cleaner, shell, castle, rocket and shovel.
Appendix J (continued)


11. nail, lawn mower, girl, rose, chicken, ball, foot. Picture contains: nail, lawn mower, girl, rose, chicken, ball, foot, fly, tiger, chimpanzee, house and cot.

12. monkey, shell, ant, radio, woman, parrot, pencil sharpener. Picture contains: monkey, shell, ant, radio, woman, parrot, pencil sharpener, motorcycle, hose, frog, net and number seven.

13. slide, trumpet, breakfast, broom, bucket, scales, suit, peg. Picture contains: slide, trumpet, breakfast, broom, bucket, scales, suit, peg, boat, stapler, boot, lion and well.

14. water bottle, ruler, turtle, shoe, safety pin, carrots, salt shaker, record player.
   Picture contains: water bottle, ruler, turtle, shoe, safety pin, carrots, salt shaker, record player, rattle, seal, wagon, apple and star.