# MEMORY AND SPEED OF PROCESSING IN GENERAL GIFTED AND EXCELLING IN MATHEMATICS STUDENTS

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*The present study examined the memory and speed of processing abilities associated with general giftedness (G) and excellence in mathematics (E). The research involved four groups of 16-18 years old participants varying in levels of G and E. 160 participants were tested on a battery of three memory tests and five speed of processing tests. Working-memory was found to be related to both G and E factors. The results reveal that G factor is related to high short term memory and that E factor is associated with high visual-spatial memory. Gifted students who excel in mathematics (G-E group) outperformed in all speed of processing tasks compared to the other three participants groups. The results can contribute to the theoretical knowledge about similarities and differences in memory and speed of processing abilities in G and E groups.*

**Key words**: general giftedness, excellence in mathematics, Memory abilities, Speed of processing

## INTRODUCTION

Despite increasing interest in gifted students and their education, little empirical data is available concerning the cognitive skills of gifted individuals who excel in mathematics. To date much of the research on the relation between different cognitive abilities and mathematical competencies has been conducted on low mathematics achievement students (e.g., Swanson & Jerman, 2006). Few studies examined highly mathematically gifted adolescents (e.g Dark & Benbow, 1991; Swanson, 2006). Studies about mathematical ability and memory were undertaken mostly on children in elementary school (e.g., Hoard et al., 2008 ; Bull & Johnson, 1997; Smedt et al., 2009) while few examined high school students (e.g Dark & Benbow, 1991). The contribution of speed of processing to mathematical excellence was also examined in several studies (Fry & Hale, 1996; Hoard et al., 2008;) but no study has yet examined the associations between general giftedness (G) and excellence in mathematics (E), as regards memory and speed of processing abilities.

## BACKGROUND

### General giftedness, Memory and Speed of processing

Earlier studies identified a connection between measures of intelligence and Working Memory (WM) or Short Term Memory (STM). For example, Ackerman, Beier & Boyle (2005) conducted a meta-analysis of the literature from 1872 through 2002 that examined the relationships between WM / immediate memory (i.e., STM) and intelligence. The study revealed a correlation between measures of STM and general ability and perceived a link between simple span memory and intelligence. Earlier similar results were received by Carroll (1993) who demonstrated an average correlation between immediate memory factors (i.e. tasks requiring storage and retrieval of information) and general ability.

In addition, a number of researches have focused on the hypothesis that speed of processing is part of the intelligence. The faster the speed of processing the higher the IQ score (Deary, 1993; Deary, 2000; Finkle & Pederson, 2000).Vernon (1983) investigated the relationship between a number of measures of speed of cognitive information-processing and (WISC-Wechsler Adult Intelligence Scale and the Raven Advanced Progression Matrices) scores in the tests on intelligence. The results suggested that the speed factor accounts for 65.5% part of the variance in intelligence scores. The conclusion was that individual differences in intelligence can be attributed, to a moderate extent, to variance in the speed or efficiency with which these operations are performed.

A considerable amount of recent evidence suggests that elemental speed of processing abilities (e.g., encoding speed, efficiency of short-term memory storage and processing, and simple and choice reaction time) may be related to intellectual giftedness (Kranzler, Whang & Jensen, 1994; Dark & Benbow, 1991; Vernon, 1983). As to relationships between giftedness and memory ability, some studies demonstrated that gifted children display a higher rate of memory capacity compared to their non-gifted peers (Harnishfeger & Bjorklund, 1990; Gaultney, Bjorklund, & Goldstein, 1996). For example, Calero et al. (2007) compared WM capacity between children with high and average IQ aged 6 to 11 years and found that high IQ children had significantly higher scores on WM than their average-intelligence coevals.

**Excelling in Mathematics, Memory and Speed of processing**

Memory abilities are thought to be critical to many aspects of mathematical learning (e.g., Meyer et al., 2009). In particular, WM storage is regarded as being essential to the solution of complex (multi-step) arithmetical problems (Hoard et al., 2008). Children who excel in early mathematics learning tend to have high WM capacity (Hoard et al., 2008; Meyer et al., 2009; Passolunghi, Mammarella & Altoe, 2007). Dark & Benbow (1991) showed that individual differences in WM span were associated with intellectual giftedness in mathematics. Testing intellectually gifted 13 and 14 year-olds, they found that mathematics achievement was related to enhanced performance on a WM span task with digits and tasks on location of stimuli, whereas verbal precocity was related to enhanced performance with word stimuli. Additionally, Hoard et al. (2008) found that intellectually gifted individuals had an advantage in visual-Spatial memory (VSM).

Speed of processing seems to be important as a predictor of variations in arithmetic performance (Durand, Holme Larkin & Snowling, 2005; Fry & Hale, 1996; Hoard et al., 2008). Bull & Johnston (1997) found that processing speed, as measured by visual matching, crossing out tasks, and perceptual motor speed, was a unique predictor of arithmetic skills independent of reading ability for 7 years old children. Taub, Floyd, Keith & McGrew (2008) showed that processing speed was significantly related to quantitative knowledge for children at ages 9 to 13.

Some studies examined the contribution speed of processing and short-term memory to arithmetic calculation (Berg, 2008; Johnson et al., 2003; Geary & Brown, 1991). Case and colleagues (1982) found a linear relationship between speed of processing and storage capacity of the working memory. In a study of 6 to 11 year olds, they reported that faster counting speed predicted higher counting spans. The explanation for these results is that the faster a child processes relevant information, the more information the child can retain over a short period of time.

Accordingly, this study examined the memory and speed of processing abilities associated with factors of general giftedness and excelling in mathematics. The purposes of the present study were as follows:

1. To examine which memory abilities are associated with G and E factors

2. To examine the differences in speed of processing among students according to G and E factors.

## METHOD

### Participants

We report herein our findings on 160 $10^{th}$ -$12^{th}$ grade students (16-18 years old) right-handed male and female students who were recruited for the study (see Table 1). The participants were subdivided in four experimental groups, determining the research population by a combination of E and G factors:

G-E group: students who are identified as generally gifted and excelling in mathematics;

G-NE group: students who are identified as generally gifted but do not excel in mathematics;

NG-E group: students excelling in mathematics who are not identified as generally gifted;

NG-NE group: students who are neither identified as generally gifted nor excelling in mathematics.

| | Excelling in mathematics (E)<br>SAT-M >26 or HL in mathematics with math score > 90 | Non-excelling in mathematics (NE)<br>SAT-M <22 and RL in mathematics with math score>90 or HL in mathematics with math score < 80. | Total |
|---|---|---|---|
| Gifted (G)<br>Raven > 27 | 34 | 36 | 70 |
| Non-Gifted (NG)<br>Raven < 26 | 44 | 46 | 90 |
| Total | 78 | 82 | 160 |

**Table 1: Description of study groups**

**Tasks and Materials**

Memory abilities tests:

1. Short-Term Memory - Digit Span test (WISC III; Wechsler, 1997)

The test involves two parts: during the first phase the participant is asked to listen to random digits read out loud and then to repeat the digits in the same order. If the participant recalls the digits correctly, another trial is administered. Successive trials are administered using random digits increased by one digit and so forth until the participant fails two attempts. The maximum possible span is nine digits.

During the second phase the participant is asked to listen to a random set of digits read out loud and then to repeat the digits backwards. If the participant recalls the digits correctly, another trial is administered. Successive trials are administered using random digits increased by one digit and so forth until the participant fails two attempts. The maximum possible span is eight digits. The measure of both test parts was a standard score based on Israel's norm scale scores (from Hebrew version of WISC III).

2. Working Memory for Digits and Letters test (WISC III; Wechsler, 1997)

The participant is asked to listen to a mixed series of letters and digits and then to rearrange them by first repeating the digits in the correct order, and then the letters in the correct order. If the participant recalls the digits and letters correctly, another trial is administered. Successive trials are administered using random digits increased by one letter or digit and so forth until the participant fails two attempts. The maximum possible span is eight letters and digits. The measure of the test was a standard score based on Israel's norm scale scores (from Hebrew version of WISC III).

3. Visio-Spatial Working Memory test (Corsi, 1972)

This block recall task consists of ten blocks arranged randomly on a wooden board. The test involves two parts: during the first part the researcher points at a sequence of blocks at a rate of one per second. After the researcher completes indicating the sequence, the participant is asked to replicate the sequence. If the participant recalls the sequence of blocks correctly, another trial is administered. Successive trials are administered adding one more block each time and so forth until the participant fails two successive attempts. The maximum possible span is ten blocks.

During the second part, the researcher points at a sequence of blocks at a rate of one per second. After the researcher completes indicating the sequence, the participant is asked to replicate the sequence backwards. If the participant recalls the sequence of blocks correctly, another trial is administered. Successive trials are administered adding one more block each time and so forth until the participant fails two successive attempts. The maximum possible span is ten blocks. The measure of both test parts was a standard score according to the accepted Israeli scale (from Hebrew version of Visio-Spatial Working Memory test).

Speed of processing tests:

1. Visual- matching test (Woodcock-Johnson Tests of Cognitive Ability, 2001)

The test consists of rows that include one target symbol and 19 additional symbols. The participant has to circle all the symbols that are identical to the target symbol. The time limit for the assignment is 120 seconds.

2. Cross out of numbers test (Woodcock-Johnson Tests of Cognitive Ability, 2001)

The test consists of 60 rows, each with six numbers. The participant has to circle two identical numbers in each row. The time limit for the assignment is 120 seconds.

3. Digit-symbol test (WISC III, 1997)

The test consists of a code table displaying pairs of digits and symbols, and rows of double boxes with a digit on the top box and nothing on the bottom box. The participant has to use the code table to determine the symbol associated with each digit (the test consists 133 digits), and to write as many symbols as possible in the empty boxes below each digit. The time limit for the assignment is 120 seconds.

4. Symbol-search (WISC III, 1997)

The test consists of rows marked by one target symbol and five additional symbols. The participant has to decide if the target symbols appear in the row of symbols and to mark YES or NO accordingly. The test consists of 60 items and the participant has to mark as many items as possible within 120 second.

5. Simple arithmetic exercises (Openhaim-Bitton, 2003)

The participant has to solve as many simple arithmetic exercises as possible within two minutes. The accuracy and number of right answers will be examined.

The depended variables in each test were: accuracy (in %) of correct answers.

**Data Analysis**

To investigate the questions addressed in this study, multivariate analysis of variance tests (MANOVA) were used to compare the scores of participants in each test. The between-subjects factors were: G and E factors and the within-subjects factors were the scores on each memory and speed of processing tests.

## RESULTS

### Memory tests

MANOVA revealed two significant effects. First, the main effect of the G factor ($F(3,150) = 4.32$, $p < .05$) was obtained. In this case, univariate ANOVA tests showed the source of differences between the groups is STM test ($F(1,152) = 12.20$, $p < .01$) in which G students achieved higher (*M*=12.6, *SD*=2.7) STM scores as compared with NG students (*M*=10.7, *SD*=2.4). Results of performance on the memory tasks (means and standard deviations) are presented in Table 2.

| | | E | | NE | |
|---|---|---|---|---|---|
| | | *M* | *SD* | *M* | *SD* |
| G | STM | 12.8 | 2.7 | 12.4 | 2.8 |
| | WM | 10.6 | 2.2 | 10.8 | 2.7 |
| | VSM | 12.5 | 2.1 | 11.8 | 1.5 |
| NG | STM | 10.9 | 2.3 | 10.5 | 2.5 |
| | WM | 10.8 | 2.7 | 9.7 | 2.2 |
| | VSM | 12.0 | 2.5 | 11.3 | 2.2 |

Note: G=Gifted; NG=Non-Gifted; E=Excelling; NE= Non-Excelling; M=Males; F=Females STM=Short-Term Memory; VSM= Visual-Spatial Memory; WM= Working Memory

**Table 2: Performance of participants on three memory tests: standard scores for correct answers in each memory test**

Additionally, a main effect of the E factor was found to be marginally significant on the VSM score ($F(1,152) = 3.65$, $p < .06$). In this case, E students scored higher (*M*=12.2, *SD*=2.3) than NE students (*M*=11.5, *SD*=1.9).

An interaction effect of G × E factors was found with regard to the WM total score ($F_{(3,152)} = 3.22$, $p < .05$). The WM scores of E students were similar in G (*M*=10.6, *SD*=2.2) and NG students (*M*=10.8, *SD*=2.7). However, the WM scores of NE students were significantly higher for G (*M*=11.7, *SD*=2.4) than for NG students (*M*= 9.7, *SD*=2.2).

**Speed of processing tests**

MANOVA revealed an overall significant main effect for G factor ($F(5,149)=2.50$, $p < .05$) and E factor ($F(5,149) = 4.35$, $p < .01$). In this case, univariate ANOVA tests showed the source of differences between the groups is Cross out of numbers and Simple arithmetic exercises tests. In this case, G students outperformed NG students and E students were more accurate than NE students in both tests (see also Table 3).

Additionally, univariate ANOVA tests showed an interactions between G × E factors with regard to Symbol-search test ($F(1,153)=4.11$, $p < .05$) and Digit-symbol tests $F(1,153)=5.88$, $p < .05$). The accuracy of NG students in both tests was similar in E and NE students. However, the accuracy of G students in both tests was significantly higher for E than for NE students (see also Table 3).

| | | E | | NE | |
|---|---|---|---|---|---|
| | | *M* | *SD* | *M* | *SD* |
| G | Visual matching | 68.3 | 12.3 | 61.1 | 14.8 |
| | Cross out of numbers | 75.2 | 6.2 | 71.1 | 5.6 |
| | Digit-symbol | 67.0 | 11.4 | 61.7 | 10.0 |
| | Symbol-search | 76.0 | 12.4 | 69.7 | 12.0 |
| | Simple arithmetic exercises | 97.0 | 5.0 | 89.8 | 10.8 |
| NG | Visual matching | 61.1 | 11.2 | 62.4 | 11.6 |
| | Cross out of numbers | 70.2 | 8.4 | 68.4 | 10.0 |
| | Digit-symbol | 63.7 | 7.6 | 65.1 | 9.3 |
| | Symbol-search | 70.9 | 9.1 | 71.9 | 11.2 |
| | Simple arithmetic exercises | 92.3 | 9.8 | 83.6 | 14.6 |

**Table 3: Performance of participants (in %) on five speed of processing tests**

## CONCLUSIONS

The aim of the present study was to examine the memory and speed of processing abilities associated with general giftedness (G) and excelling in mathematics (E).

Results showed that there are different memory abilities that associate with G and E factors.

The findings revealed that G is related to high STM ability and the E factor was found to be linked with high VSM. In addition, the results demonstrated that the WM scores of students excelling in mathematics were comparable in G and NG individuals. However, the WM scores of NE students were significantly higher for G students compared to NG students.

The results regarding speed of processing tasks show that the gifted students who excel in mathematics (G-E group) outperformed in these tasks compared to the other three participant groups. The findings discerned however discrepancies between tests: in some tests a difference in performance was associated with both G and E factors while in other tests, only G factor was associated with the differences between the groups.

The findings received in the study partly support previous observations and suggests that memory and speed of processing abilities seems to be an important factors in explaining mathematical giftedness. The findings add to the theoretical knowledge pertaining to the cognitive processing of gifted students excelling and non-excelling in mathematics, and can enlighten educators and instructional designers enabling them to better plan educational effective programs tailored to suit the unique educational needs of gifted students excelling in mathematics. With this in mind, educational programs for G-E students, should address the observation that these students have high abilities in visual-spatial memory and in information processing and implement the use of visual aids in teaching mathematics in gifted classes.

## REFERENCES

Ackerman, P. L., Beier, M. E., & Boyle, M. O. (2005). Working memory and intelligence: The same or different constructs? *Psychological Bulletin,* 131 (1), 30-60.

Berg, D.H. (2008). Working memory and arithmetic calculation in children: The contributory roles of processing speed, short-term memory, and reading. Journal of Experimental Child Psychology, 99, 288–308.

Bull, R., & Johnston, R.(1997). Children's arithmetical difficulties: Contribution from processing speed, item identification, and short-term memory. Journal of Experimental Child Psychology, 65, 1–24.

Calero, M.D., García-Martín, M. B., Jiménez, M. I., Kazén, M., & Araque, A. (2007). Self-regulation advantage for high-IQ children: Findings from a research study. Learning and Individual differences, 17(4), 328-343.

Carroll, J. B. (Ed.). (1993). Human cognitive abilities: A survey of factor-analytic studies. New York: Cambridge University Press.

Case, R., Kurland, D. M., & Goldberg, J. (1982). Operational efficiency and the growth of short term memory span. Journal of Experimental Child Psychology, 33, 386–404.

Corsi, P. M. (1972). Human memory and the medial temporal region of the brain. Dissertation Abstracts International, 34 (02), 819B. (University Microfilms No. AAI05-77717).

Dark, V.J., & Benbow, C.P. (1991). Differential enhancement of working memory with mathematical versus verbal precocity. Journal of Educational Psychology, 83, 48–60.

Deary, I. J. (1993). Inspection time and WAIS-RIQ subtypes: A confirmatory factor analysis study. Intelligence, 17(2), 223-236.

Deary, I. J. (2000). Simple information processing and intelligence. In R. J. Sternberg (Ed.), Handbook of intelligence (pp. 267-284). Cambridge, UK: Cambridge University Press.

Durand, M., Hulme, C., Larkin, R., & Snowling, M. (2005). The cognitive foundations of reading and arithmetic skills in 7-to 10 year olds. Journal of Experimental Child Psychology, 91, 113–136.

Finkle, D., & Pedersen, N. L. (2000). Contribution of age, genes and environments to the relationship between perceptual speed and cognitive ability, Psychology and Aging, 15(1), 56-64.

Fry, A., & Hale, S. (1996). Processing speed, working memory, and fluid intelligence: Evidence for developmental cascade. Psychological Science, 7, 237–241.

Gaultney, J.F., Bjorklund, D.F., & Goldstein, D. (1996). To be young, gifted, and strategic: Advantages for memory performance. Journal of Experimental Child Psychology, 15, 346-363.

Geary, D.C., Frensch, P.A., & Wiley, J.G. (1993). Simple and complex mental subtraction: Strategy choice and speed of processing differences in younger and older adults. Psychology and Aging, 8(2), 242−256.

Harnishfeger, K.K., & Bjorklund, D.F. (1994). A developmental perspective on individual differences in inhibition. Learning and Individual Differences, 6(3), 331-355.

Hoard, M.K., Geary, D.C., Byrd-Craven, J., & Nugent, L. (2008). Mathematical cognition in intellectually precocious first graders. Developmental Neuropsychology, 33 (3), 251–276.

Johnson, J., Im-Bolter, N., & Pascual-Leone, J. (2003). Development of mental attention in gifted and mainstream children: The role of mental Capacity, Inhibition, and Speed of Processing. Child Development, 74 (6), 1594-1614.

Kranzler, J. H., Whang, P. A., & Jensen, A. R. (1994). Task complexity and the speed and efficiency of elemental informational processing: Another look at the nature of intellectual giftedness. Contemporary Educational Psychology, 19, 447-459.

Meyer, M.L., Salimpoor, V.N., Geary, D. C., & Menon, V. (2009). Differential contribution of specific working memory components to mathematics achievement in 2nd and 3rd graders. Learning and Individual Differences, 20(2). 101-109.

Openhaim-Bitton, S. (2003). Arithmetic two-minute test. Unpublished test. University of Haifa.Haifa.

Passolunghi, M. C., Vercelloni, B., & Schadee, H. (2007). The precursors of mathematics learning: Working memory, phonological ability, and numerical competence. Cognitive Development, 22, 165–184.

Smedt, B. D., Janssen, R., Bouwens, K., Verschaffel, L., Boets, B., & Ghesquière, P. (2009). Working memory and individual differences in mathematics achievement: A longitudinal study from first grade to second grade. Journal of Experimental Child Psychology, 103, 186–201.

Swanson, H. L. (2006). Cognitive processes that underlie mathematical precociousness in young children. Journal of Experimental Child Psychology, 93, 239–264.

Swanson, H. L. & Jerman, O. (2006). Math Disabilities: A Selective Meta-Analysis of the Literature, Review of Educational Research, 76(2), 249-274.

Taub, G. E., Floyd, R. G., Keith, T. Z., & McGrew, K. S. (2008). Effects of general and broad cognitive abilities on mathematics achievement. School Psychology Quarterly, 23 (2), 187–198.

Vernon, P. A. (1983). Speed of information processing and general intelligence. Intelligence, 7, 53-70.

Wechsler, D. (1997). Wechsler Intelligence Scale for Adults (WAIS-III). San Antonio, Tx: Harcourt Assessment Inc.

Woodcock, R. W., McGrew, K. S., & Mather, N. (2001). Woodcock-Johnson III Tests of Cognitive Abilities. Itasca, IL: Riverside Publishing.