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Ninth Graders' Spatial Ability and Working Memory Capacity (WMC) in Relation to their Science and Mathematics Achievement and their Gender

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ABSTRACT

The purpose of the current study is to compare high and low achievers in science and mathematics in terms of their spatial ability and Working Memory Capacity (WMC), and to compare male and female learners' performance in both these two cognitive abilities and their science and mathematics achievements. The sample consisted of 102 ninth graders in Oman. To estimate participants' spatial ability and their WMC, the Water Level Task (WLT) and the Digit Span Backwards Test (DSBT) were used. The results indicated that both science and mathematics high achievers significantly outperformed low achievers in terms of spatial ability and WMC. In addition, females out-performed males in WMC, while males outperformed females in spatial ability. There were no significant differences between the two genders in terms of their achievement in science and mathematics.

Key Words: Spatial Ability; Water Level Task (WLT); Working Memory Capacity (WMC); Science and Mathematics Achievement; Gender Differences.

INTRODUCTION

Scientific and mathematically literate individuals are essential to the economic well-being of a country and its quality of life. Studies have shown that underachievement in science and mathematics is considered to be an obstacle to progress in higher education and to career acquisition (Ashcraft & Krause, 2007; National Science Foundation (NSF), 1999). In addition, succeeding in science and mathematics can enhance students' self-confidence and intrinsic motivation (Özgün-Koca & Şen, 2011). Al Orime & Ambusaidi (2011) assert that science and mathematics exhibit similar attributes such as idealism, openness, the importance of understanding and the logic-imagination interaction.

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Moreover, cognitive processes such as spatial ability, working memory, mental capacity and processing efficiency play a significant role in enhancing achievements in science and mathematics (Alamolhodaei, 2009; BouJaoude, Salloum & Abd-El-Khalick, 2005; Halpern et al., 2007; Panaoura & Panaoura, 2006). In order to carry out scientific or mathematical investigations, students need to perform several cognitive processes such as analyzing data, constructing mental and mathematical models, thinking spatially, validating procedures, manipulating variables and evaluating evidences (National Research Council (NRC), 1996 & 2000; American Association for the Advancement of Science (AAAS), 1993 & 1990). Therefore, studying the factors that are related to science and mathematics achievement, especially those of a cognitive nature, is important. Thus, emerging insights about particular implications for pedagogical practice can be provided.

To empower conceptualization, meaningful learning should be associated with its degree of relevance to students' prior knowledge and real-life learning experiences. Failing to prepare for such experiences can cause conceptual difficulties (Glynn & Duit, 1995; Koch, 1999; Lesh, Lester & Hjalmarson, 2003; Mintzes, & Wandersee, 1998; Novak, 1998). Several science and mathematics concepts are abstract and are sometimes presented in meaningless contexts that require cognitively challenging processing (Ashcraft & Krause, 2007; Cramer, 2003; Halpern et al., 2007; Pozzer & Roth, 2005). One important source of abstraction is the spatial nature of numerous science and mathematics concepts. Spatial reasoning, which involves constructing spatial relations between objects and performing simplifying spatial transformations, is essential to comprehend and reflect on both physical phenomena and mathematical problems (Clement, 2008; Clements, 1998; Mathewson, 1999; Rohde & Thompson, 2007). In addition, conceptualizing science and mathematics concepts demands a satisfied level of mental capacity (BouJaoude, Salloum & Abd-El-Khalick, 2005; Niaz & Robinson, 1991). Working memory capacity (WMC) is an example. It has beren found to be a significant predictor of individuals' performance in problem solving (Ashcraft & Krause, 2007; Bühner, Kröner, & Ziegler, 2008).

A related issue is gender differences in science and mathematics. The results of the Trends in International Mathematics and Science Study (TIMSS) show that males tend to score higher than females in science and mathematics in most countries (Halpern et al., 2007; National Center for Education Statistics (NCES), 1997). Females are also often discouraged from participating in advanced level in science and mathematics. As a result, women are under-represented in science and engineering degrees. The percentage of men who earn a degree in science or engineering is noticeably larger than that of women (Halpern et al., 2007; Jacobs & Simpkins, 2005). These gender differences contribute to essential social problems (Pettitt, 2004). Women who discontinue their mathematical studies earlier than men may be less likely to secure high-status careers that rely on mathematics knowledge (Watt, 2005).

During middle school, a gender gap in science interests emerges with boys being gradually more interested in physics and girls more interested in biology (Özgün-Koca & Şen, 2011). This gap broadens over 20-fold by the end of high school (Baram-Tsabari & Yardern, 2011). While, some studies have shown that males have more positive attitudes towards science and mathematics than females, other studies did not find these differences (Özgün-Koca & Şen, 2011). Females also have more mathematics anxiety than males (Karimi & Venkatesan, 2009). Females' self perceptions regarding their own science/mathematics talent have a significant relationship with their mathematics achievement (Linver & Davis-Kean, 2005; Potvin, Hazari, Tai & Sadler, 2009; Watt, 2005). This relationship was weaker for the males. Boys seem to be more interested in mathematics and engage more actively in mathematics-related tasks. On the other hand, girls' participation is greater if it is combined with socially meaningful and personally related tasks (Watt, 2005). They, for instance, have a higher intrinsic motivation than boys for extracurricular zoological learning experiences. Girls, who perceived themselves as more competent, enjoyed these types of activities more and experienced more affiliation (Bätz, Wittler & Wilde, 2010).

Females' disinterest in mathematics has a serious pedagogical educational consequence and results in, for instance, raising the anxiety of kindergarten teachers to teach mathematics (Bintaş, 2008). This consequently lowers their female students' mathematics achievement (Beilock, et al., n.d.). Mathematics anxiety has been shown to hinder mathematics performance and slow cognitive processing (Ashcraft & Krause, 2007; Karimi & Venkatesan, 2009). However, when a mathematics learning environment is designed to be more collaborative, relevant and meaningful, kindergarten pre-service teachers, for instance, tend to become more self-confident and develop more positive attitudes towards mathematics teaching (Bintaş, 2008).

Investigating gender differences in science and mathematics will contribute to understanding females' underachievement and promoting their choices to pursue science and mathematics related careers. Furthermore, the evidence of the pedagogical importance of both spatial ability (Clement, 2008; Clements, 1998; Pribyl & Bodner, 1987; Sanchez, & Wiley, 2006) and working memory capacity (Johnstone & Al-Banna, 1986, 1989; Johnstone, Hogg & Ziane, 1993) have directed researchers' attention and efforts towards investigating gender differences in science and mathematics. However, research on the interplay between these two cognitive abilities and the achievement of both genders in science and mathematics merits considerably more examination. Thus, this is the focus of this study.

Spatial Ability

Although there are many definitions of spatial ability, it is generally thought to be related to skills involving the retrieval, retention and transformation of visual information in a spatial context (Lohman, 1993; Velez, Silver & Tremaie, 2005). It includes the ability to manipulate the information represented in visual or graphical forms (Diezmann & Watters, 2000). Halpern (1986, 48) explains that spatial ability is the ability to imagine what an irregular figure would look like if it is rotated in space. She adds that it is the ability to discern the relationship between shapes and objects.

Several studies indicate that high spatial ability students outperform low spatial ability students in science and mathematics when the test items involve geometrical and representational manipulations as well as higher order problem solving (Black, 2005; Carter, Larussa & Bodner, 1987; Kozhevnikov, Motes & Hegarty, 2007; Mcleay, 2006; Pribyl & Bodner, 1985; Rudmann, 2002; Sanchez & Wiley, 2006). Thus, when an exam does not involve complicated spatial transformations, the relationship between spatial ability and achievement is not significant (Stieff, Bateman, & Uttal, 2005). High spatial learners manage to deal with more than one motion vector, switch frames of reference, and interpret kinematics graphs when solving kinematics problems (Kozhevnikov, Motes & Hegarty, 2007). They also have a higher level of interest in learning science and mathematics than low spatial learners (Lord & Nicely, 1997). In addition, learners' spatial abilities and their spatial experience affect the nature of their mental images which they construct for unobservable scientific entities. For example, learners' concrete experience with spatial objects shapes their mental images and influences their ability to imagine scientific microscopic entities in dynamic motion (Al-Balushi, 2009). Some learners tend to doubt the credibility of scientific representations that illustrate microscopic entities such as molecules, atoms, and electrons because of the high visuospatial mental demand required to imagine these entities. Some other learners even deny the existence of these entities for the same reason (Al-Balushi, 2011).

Previous studies show that males generally outperform females in spatial ability (Halpern, 1992; Halpern et al., 2007; Hyde, 2005; Kaufman, 2007; Roberts & Bell, 2002; Thomas & Turner, 1991; Vecchi, 2000). Some other studies did not identify this gender difference (Lord & Nicely, 1997; Seng & Tan, 2002; Stieff, Bateman, & Uttal, 2005). Roberts and Bell (2002) conclude that gender differences in spatial ability do not exist until adolescence. Halpern et al. (2007) theorize that gender differences in spatial abilities exist for problems which are spatial in nature, whereas no differences occur when problems do not require spatial abilities. Some researchers (e.g. Halpern et al., 2007; Stieff, Bateman & Uttal, 2005) also assert that experience has a major role in enriching spatial ability and that gender bias can be eliminated by long-term training. Stieff and his colleagues designed a computer-based program to assist biochemical students in understanding spatial structures in complex molecules, which allowed them to construct their own molecular visual representations in order to achieve an understanding of the spatial properties of molecules.

There are a variety of spatial tasks used to measure spatial ability in general or to measure specific spatial factors. Examples of these tasks are: mental rotation, paper folding and water level judgments (Blasko et. al., 2004). This study uses the Water Level Task (WLT).

Water Level Task

The Water-Level-Task (WLT) was developed by Piaget and Inhelder (cited in Li (2000)) to assess the nature of children's perception of space within a Euclidean reference system. The original WLT experiment was designed to explore how children gradually develop an external frame of reference to organize spatial experience and describe orientation and coordination in space (Ackermann, 1991). In the WLT, the subject is required to anticipate the water surface level in a bottle which is presented in different stationary directions. Despite the orientation of the container, an accurate response requires the individual to recognize that the water level surface must remain parallel to the surface of the earth.

Although the WLT was originally designed to study children's thinking, some adults fail to do this task despite encountering liquid in tilted containers every day. The source of this failure is still not well understood (Vasa & Liben 1996). In his review of studies of the WLT, Pulos (1997) reports that approximately 40% of college students and 60% of non-college adults fail the task.

The vast majority of the research into individual differences in the WLT has focused on the components related to the spatial aspects of the task. This focus on the spatial component is so ubiquitous that many consider the WLT to be a spatial task. A strong relationship between spatial ability and performance on WLT has been well-documented (Hirvasoja, 2004; Li, 2000; Li, 2001; Linn & Peterson 1986; Pascual-Leone & Morra 1991). Specific prior knowledge also plays a role in individuals' performance on the WLT. Pulos (1997) emphasizes that explicit knowledge of gravity is a source of individual differences on the WLT and other spatial tasks. He found that there was a strong relationship between gravity-based explanations of physical science-related college majors and their performance on the WLT. This relationship did not exist for community college students who had much less physical science background. Various authors have also concluded that for individuals to perform successfully on the WLT, they need to develop a strong Euclidean spatial system and to reach the formal operational thinking level. Thus, many children do not perform well in the WLT before adolescence (Li, 2000).

While some studies have established a significant out-performance of males over females in the WLT (Li, Nuttall, & Zhao, 1996; Roberts & Bell, 2002; Thomas & Turner, 1991), some other studies have found no significant differences between genders in the WLT (Pulos, 1997; Seng & Tan, 2002). The age-factor seems to play a significant role in this gander-related issue. Roberts and Bell (2002) found that, while men performed better than women in the WLT, there were no significant differences between girls and boys. Taking culture into consideration, Chinese students outperform American students in the WLT (Li, Nuttall, & Zhao, 1996), and among Chinese American men, those who write Chinese outperform those who do not (Li, Nuttall, & Zhao, 1999). Chinese students also do significantly better than Malay students (Seng & Tan, 2002).

Working Memory in Science and Mathematics Education

Generally, Working Memory Capacity (WMC) is thought to be a limited capacity system responsible for coordinating information for processing tasks, storing and integrating task-relevant information, and inhibiting the interference of task-irrelevant information while performing cognitive tasks (St Clair-Thompson & Botton, 2009; Yuan, et al., 2006). Working memory receives information and temporarily holds it before a response is made. This allows time for processing a wide range of cognitive tasks such as thinking, reasoning and manipulation before passing the information to the long-term memory (Alamolhodaei, 2009; Baddeley, 2006; Johnstone, 2006). Individuals with limited WMC are disadvantaged with regard to their cognitive processing efficiency. An overloaded WMC limits a learner's space to think and organize information in a meaningful manner, and the learner may consequently fail to perform cognitive tasks successfully. When a learner exceeds her/his WMC, a sharp drop in performance is noticed (Alamolhodaei, 2009; Johnstone & El-Banna, 1989; Panaoura & Panaoura, 2006).

Past research generally supports a significant positive relationship between the demand on working memory and the complexity of mathematics problems. This complexity includes both the total number of steps required for problem solution and the numerical values involved in arithmetic operations (Alamolhodaei, 2009; Ashcraft & Krause, 2007; Panaoura & Panaoura, 2006). Working memory capacity is also highly correlated with overall science achievement (Gathercole, et al., 2004; Solaz-Portoles & Lopez, 2007; St Clair-Thompson & Botton, 2009) as well as specific problem solving, such as conceptual problems, chemical equilibrium problems, organic chemistry synthesis problems, and physics problems (Johnstone & El-Banna, 1989 & 1986; Johnstone, Hogg, & Ziane, 1993; St Clair-Thompson & Botton, 2009). Scientific problems that require more than one mental representation at a given time demand a higher level of working memory capacity than simple problems (Solaz-Portoles & Lopez, 2007).

As the mental demands of the problem increases, mental capacity becomes a better predictor of performance than formal operational reasoning. High mental demand problems require more mathematical transformation skills and more memory schemes. This puts more load on the working memory (BouJaoude, Salloum & Abd-El-Khalick, 2005). Highly mentally demanding problems, such as addition problems with carrying, might also increase a learner's anxiety. This consequently increases reaction time and means that the performance level tends to drop (Ashcraft, 2002). In addition, high anxiety obstructs high working memory learners' spatial ability in terms of what they are capable of achieving (Ramirez, et al., n.d.). However, extensive training may reduce the mental demands of high mental challenging problems and reduce the negative effect of cognitive variables (BouJaoude, Salloum & Abd-El-Khalick, 2005). By training and practicing, experts develop an efficient chunking system.

This chunking system reduces the load on the working memory capacity. It enhances the expansion of their working memory capacity and optimizes access to their long-term memory during problem solving (Solaz-Portoles & Lopez, 2007).

The purpose of the current study is to compare high and low achievers in science and mathematics in terms of their spatial ability and Working Memory Capacity (WMC), and to compare male and female learners' performance in these two cognitive abilities and their science and mathematics achievements. The research questions are:

1. To what extent do high achievers in science differ from low achievers in terms of their spatial ability and WMC?

2. To what extent do high achievers in mathematics differ from low achievers in terms of their spatial ability and WMC?

3. To what extent do male learners differ from female learners in terms of their spatial ability, WMC, science achievement and mathematics achievement?

METHODOLOGY

a) Participants

The participants were 102 ninth graders in Seeb region in the Sultanate of Oman. For grades 5-10, this region has eight female public schools and five male public schools. One female school and one male school were randomly selected. Two ninth grade classes were then randomly chosen from each school. This random selection of the schools and the classes within each school to participate in the study was an attempt to minimize the differences caused by the fact that they are taught by different teachers. In addition, all public schools in Oman follow the national curriculum, with identical textbooks, in-service training programs, and assessment measures. The school year is divided into two semesters. All schools use the same final exams for each semester which are prepared by the Ministry of Education. At each grade level, there is a set of assessment tools and rubrics to assess students' practical skills, classroom participation and projects. These measures are designed by the Ministry and applied by all public schools. Therefore, for these reasons, following the procedure used to select the sample of this study by random selection of schools and the participating classes seemed to enhance the representative nature of the selected sample.

The school system in Oman is composed of two main segments: the Basic Education and the Secondary Education. The Basic Education phase consists of two cycles: Cycle 1 with four years (grades 1-4) and Cycle 2 with six years (grades 5-10). The Secondary Education consists of two years: grades 11 and 12.

b) The Instruments

For the purpose of this study, two instruments were used: The Water Level Task (WLT) to estimate participants' spatial ability, and the Digit Span Backwards Test (DSBT) to measure their WMC.

The Water Level Task (WLT): The WLT was first introduced by Piaget and Inhelder (cited in Li (2000)) to predict participants' spatial ability which allows them recognize space within a reference system. The WLT consists of one main problem, designed to assess learners' spatial ability. However, the strong relationship between spatial ability and performance on WLT which has been well-documented (Hirvasoja, 2004; Li, 2000; Li, 2001; Linn & Peterson 1986; Pascual-Leone & Morra 1991) encouraged the authors to use it as an indication of learners' spatial ability. Participants need to accurately anticipate water surface orientation in half-filled tilted and straight bottles. They should draw a line to represent the water level in different bottles. Figure 1 illustrates a paper-and-pencil version of the WLT that was reproduced by the first author of this article.

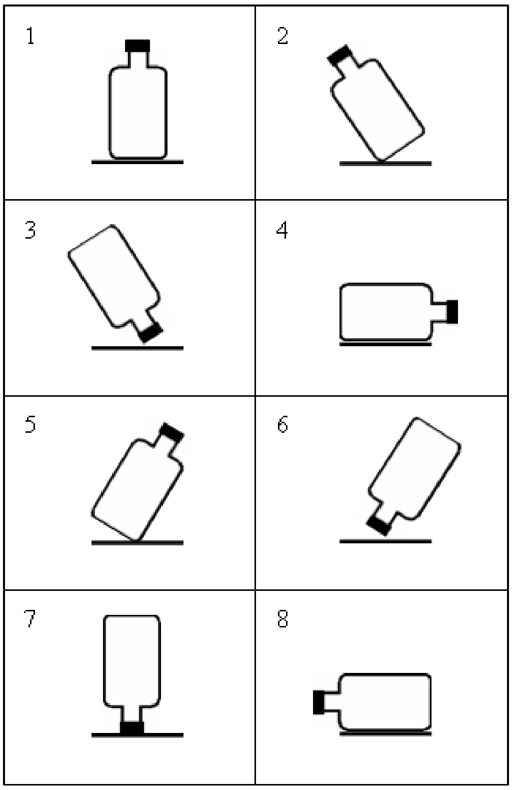

Figure 1. *The Water Level Task (WLT) in which participants are asked to draw a line in each bottle and shade in the water, assuming that these bottles are half-filled.*

The correct responses to the WLT require drawing the water level to be parallel to the floor level (the reference level). The response is considered wrong if the level line is at more than a 5^o angle to the reference level (Seng & Tan, 2002). The participant's score in the WLT is the total number of the correct responses. Therefore, the highest score in the paper-and-pencil version used in this study was (8).

This paper-and-pencil version of the WLT was first written in Arabic, the instruction language in public schools in Oman. Then it was translated into English. Two independent linguistic professors who were fluent in both Arabic and English checked the validity of the translation from Arabic to English. This process resulted in minor wording changes. The reliability of the WLT in this study was measured using a test-retest method on (21) female ninth graders. The reliability coefficient was (r=0.80).

Digit Span Backwards Test (DSBT): The DSBT is a widely used measure to estimate WMC (Alamolhodaei, 2009; Alloway, Gathercole. & Pickering, 2006; Johnstone & Al-Banna, 1986, 1989; Johnstone, Hogg & Ziane, 1993; Pickering, 2006). It is administered individually and requires the participant to recall a sequence of spoken digits in the reverse order (e.g., 4, 9, 6, 8 becomes 8, 6, 9, 4). It is composed of a sequence of blocks (Figure 2). The first block has two digits, and the subsequent blocks increase by one digit. Each block has two different sets of digits. If the participant fails to recall the first set, s/he is given another trial by reading the second set to her/him. The digits are presented one digit per second at an even and steady pace with an even monotone. The researcher keeps reading the blocks until the participant is unable to recall a particular block after two trails. The participant is given a score equals to the number of correct recalled blocks. The reliability of the DSBT in this study was measured using a test-retest method on (21) female ninth graders. The reliability coefficient was (r=0.78).

Series	1st trial	2nd trial
2	2-4	5-8
3	6-2-9	4-1-5
4	3-2-7-9	4-9-6-8
5	1-5-2-8-6	6-1-8-4-3
6	5-3-9-4-1-8	7-2-4-8-5-6
7	8-1-2-9-3-6-5	4-7-3-9-1-2-8
8	9-4-3-7-6-2-5-8	7-2-8-1-9-6-5-3

Figure 2. *The sequence of series used in the Digit Span Backwards Test (DSBT)*

c) Procedure and data collection

The WLT was first administered to the sample in their classrooms for five minutes. Then each participant was called out in a separate room to perform the Digit Span Backwards Test (DSBT). It took each participant five minutes on average to complete the DSBT which was administered by the second author.

Participants' achievement scores in science and mathematics were collected from their science and mathematics teachers at the end of the school year. Each score was out of 100 points that included: 60 points for paper-and-pencil exams and 40 points for ongoing activities which included portfolio, classroom participation and projects.

d) Data Analysis

An independent t-test analysis was used to investigate the differences between high achievers and low achievers in both science and mathematics in terms of their scores in WLT and DSBT. The same statistical test was used to investigate the differences between males and females in terms of their scores in WLT and DSBT and their science and mathematics achievements.

FINDINGS

Table 1 displays the t-test results for comparing high and low science achievers in terms of their spatial ability, as indicated by their performance in the WLT, and their Working Memory Capacity (WMC). The results show that there are significant differences between high and low science achievers in spatial ability and WMC. High science achievers outperformed low science achievers in both variables. Table 2 illustrates the t-test results for comparing high and low science achievers in terms of their spatial ability and their WMC. Similar to science, the differences between high and low mathematics achievers in terms of spatial ability and WMC are significant. High mathematics achievers outperformed low mathematics achievers in both variables.

Table 1. *t-test results for WLT and WMC by the science achievement level*

Variable	Achievement level	n	Mean	SD	df	t
WLT	Low	55	4.29	2.16	99	4.36**
	High	46	6.09	1.94		
WMC	Low	55	3.18	0.82	99	3.89**
	High	46	3.95	1.17		

** t value is significant at the 0.01 level.

Table 2. *t-test results for WLT and WMC by the mathematics achievement level*

Variable	Achievement level	n	Mean	SD	df	t
WLT	Low	58	4.33	2.12	99	4.43**
	High	43	6.16	1.96		
WMC	Low	58	3.26	0.91	99	3.16**
	High	43	3.91	1.15		

** t value is significant at the 0.01 level.

Table 3 compares males and females in WLT, WMC, science and mathematics. The t-test results show that males significantly outperform females in the WLT, whereas females significantly outperform males in the WMC. There are no significant differences between both genders in terms of science and mathematics achievements.

Table 3. *t-test results for WLT WMC and science and mathematics achievement by gender*

Variable	Gender	n	M	SD	df	t
WLT	Male	54	5.53	2.21	99	2.093*
	Female	47	4.62	2.19		
WMC	Male	54	3.26	0.78	99	2.890*
	Female	47	3.85	1.25		
Science	Male	54	71.18	14.54	99	0.380
	Female	47	72.22	12.17		
Mathematics	Male	54	71.72	16.21	99	1.595
	Female	47	66.60	15.55		

* t is significant at $\alpha \leq 0.05$

DISCUSSIONS and CONCLUSIONS

The purpose of the current study was to compare high and low science and mathematics achievers in terms of their spatial ability and Working Memory Capacity (WMC), and to compare male and female learners' performance in these two cognitive abilities and their science and mathematics achievements. The findings indicated that being competent in both cognitive abilities (spatial ability and WMC) was a characteristic of high achievers in both science and mathematics. The significant out-performance of high achievers in both science and mathematics in terms of their spatial ability supported the previous research, which emphasised the spatial nature of several science and mathematics concepts and processes (Black, 2005; Carter, Larussa & Bodner, 1987; Clement, 2008; Clements, 1998; Kozhevnikov, Motes & Hegarty, 2007; Mathewson, 1999; Mcleay, 2006; Pribyl & Bodner, 1985; Rohde & Thompson, 2007; Rudmann, 2002; Sanchez & Wiley, 2006).

Also, the significant out-performance of high achievers in both science and mathematics in terms of their WMC highlights the mental demands that an overwhelming number of mathematical processes, in both subjects, exert upon learners' mental capacity. The literature emphasises the influential role of WMC in both science and mathematics (Alamolhodaei, 2009; Ashcraft & Krause, 2007; Gathercole, et al., 2004; Johnstone & El-Banna, 1989 & 1986; Johnstone, Hogg, & Ziane, 1993; Panaoura & Panaoura, 2006; Solaz-Portoles & Lopez, 2007; St Clair-Thompson & Botton, 2009). Mathematical problems which embrace borrowing, carrying, and keeping track of sequencing operations such as long division rely heavily on working memory (Ashcraft, 2002).

Comparing males and females, the results show that male students outperform female students in WLT. Males' higher spatial abilities are well documented in the literature (Halpern et al., 2007; Hyde, 2005; Kaufman, 2007; Li, Nuttall, & Zhao, 1996; Roberts & Bell, 2002; Thomas & Turner, 1991; Vecchi, 2000). On the other hand, female students outperform male students in WMC. The Digit Span Backwards Test (DSBT) used in this study to measure the WMC is based on meaningless series of numbers (Pickering, 2006). Since females tend to perform more successfully in meaningful tasks and are attracted to less abstract activities (Bätz, Wittler & Wilde, 2010; Watt, 2005), one would expect that they would fall short in the DSBT. However, in the current study, their DSBT score was significantly higher than that of the males. This might be, in part, due to their superiority in several memory systems such as sensually detailed memory storage, episodic memory and face recognition (Gurian & Stevens, 2004; Halpern et al., 2007). Secondly, the DSBT was a verbal-based task, which tends to be a female speciality. It has been established that females have a research-based superiority in terms of verbal abilities at a range of different ages (Bätz, Wittler, & Wilde, 2010; Halpern et al., 2007), whereas visiouspatial WMC measures show males' superiority (Halpern et al., 2007).

There were no significant differences between both genders in terms of science and mathematics achievement scores. Science and mathematics achievement depends on several cognitive abilities, such as spatial abilities, verbal abilities, and working memory capacity (Halpern et al., 2007). It might be plausible to conclude that what females lack (i.e. spatial abilities) is compensated for by their high WMC and verbal performance. On the other hand, males' deficiency in WMC is compensated for by their high spatial abilities.

SUGGESTIONS

The results of this study reveal a significant feature that distinguishes high achievers from low achievers in science and mathematics. High achievers have a higher level in the two cognitive abilities investigated in the current study: spatial ability and WMC. Also, females outperform males in WMC, while males outperform females in terms of spatial ability.

These findings might support designing different pedagogical practices when dealing with these two gender groups. Females need to make more effort to enhance their spatial abilities. Past research, however, affirms that training can reduce the gap between genders in terms of spatial abilities (Halpern et al., 2007; Stieff, Bateman & Uttal, 2005). Different types of research-based training ideas, such as computer modelling, (Wu & Shah, 2004), imagining and mental manipulating of 3D objects (Lord, 1990), and sketching 3D objects (Halpern et al., 2007) are available to improve learners' spatial abilities. Further research is needed to examine these possible interventions in relation to female students' performance of spatial thinking. Also, curriculum design and instructional materials should take advantage of these pedagogical practices when constructing classroom activities.

Beside spatial abilities, training also would help reduce the gap between different groups of learners in terms of other cognitive variables such as working memory capacity (BouJaoude, Salloum & Abd-El-Khalick, 2005). Male students, based on the results of this study, need more training in learning how to lower mental demands when studying science and mathematics. They should be given a proper training to develop cognitive strategies to minimise noise or interference and to minimise mental task demands (Johnstone & El-Banns, 1986). They also need to use WMC more efficiently by using chunking strategies and by activating a proper number of schemes and connecting them together (BouJaoude, Salloum & Abd-El-Khalick, 2005; Johnstone, 2006). This might be done by relating new information to existing knowledge, presenting material in a stepwise fashion using dialogue boxes, and chunking information into meaningful units (Ashcraft & Krause, 2007; Solaz-Portoles & Lopez, 2007).

The problem of mental demand overload of problems in mathematics and mathematics-oriented problems in science might be avoided by reducing the linguistic complexity of problem statements, partitioning problem solutions into simpler steps associated with meaningful sketches, writing the relevant formulas on the board, and using different colors when writing given information, such as unknowns, equations and calculations. In addition, science and mathematics teachers can minimise cognitive overload during instruction by designing their presentations using tools such as advance organisers, concept maps, Venn diagrams, colour coding, and stepwise appearance of new information on a screen. Further research is needed to investigate the effect of these types of interventions on male students' performance on WMC measures and their science and mathematics achievements.

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