International Electronic Journal of Elementary Education
Vol.1, Issue 2, March, 2009.

On the development and measurement of spatial ability

H. Bayram YILMAZ[a]
The Ohio State University, USA

ABSTRACT

The importance of spatial ability in learning different school subjects and being successful at certain jobs has been recognized globally. The vast majority of the studies on the topic have focused on the nature of the phenomenon, the factors that affect its development), and the difference between males and females on spatial ability. However, still there is a need to conduct research studies to have a better understanding of the construct, its relations with other abilities, and the ways to foster its development. By providing a literature review, this study addresses those issues and summarizes different ways of measuring spatial ability and fostering its development to suggest study directions to future researchers.

Keywords: *spatial ability, gender differences*

Introduction

As a collection of cognitive skills that enable one interact with his environment, spatial ability has been an area of study for decades (Hegarty and Miller, 2005). Understanding the nature of the construct is crucial to increase the success rate in mathematics and science courses, which are among the most important subjects, especially to be successful at technical jobs in today's competitive work environment (Halpern, 2000; Siemankowski and McKnight, 1971). Many items asked in high-stake tests, not only country-wide selection assessments but also international comparative assessments, such as Trends in Mathematics and Science Study (TIMSS) and Program for International Student Assessment (PISA), have a common construct: spatial ability.

What is Spatial Ability?

According to Linn and Petersen (1985) spatial ability refers to "skill in representing, transforming, generating, and recalling symbolic, non-linguistic information" (p.1482).

[a] Corresponding author E-mail: bayramyilmaz@gmail.com

ISSN:1307-9298

www.iejee.com

Lohman (1993) defined the visual ability as "the ability to generate, retain, retrieve, and transform well-structured visual images" (p.3). Oliveira (2004) draws attention to the fact that spatial ability is included in most of the multiple aptitude batteries; however, there are contradictions in the spatial domain literature, which makes the topic difficult to understand. She summarized those contradictions as follows:

1. While there are same descriptions under different names, there are identical names for different components of spatial ability.
2. Number of underlying components/factors of spatial ability varies by researchers - ranging from two to ten.
3. Factor names vary across authors and even within a work of the same author.
4. Confusion exists among the researchers regarding the names and contents of a variety of spatial ability tests.

Based on their literature review on spatial ability, Cooper and Mumaw (1985) concluded that "… literature is quite clear in showing that a broadly defined spatial factor exists independently of verbal and quantitative factors" (p.71). Although there is an agreement between the researchers that spatial ability is an important component of the intellectual ability, there is no consensus on the nature of the phenomenon. As Linn and Petersen (1985) indicated that spatial ability is not a unitary construct, but it is combination of sub-skills such as using maps, solving geometry questions, and recognizing two dimensional representation of three-dimensional objects. Carroll (1993) stated that "considerable confusion exists about the identification of factors in this domain tests do not always load consistently on distinct factors, or they load rather indiscriminately on a number of factors" (p.308). Therefore, different kinds of spatial abilities have been proposed based on factor analytic studies.

The factor structure of spatial ability has been an area of study since the mid-1940s; however, those studies did not provide a clear picture of the underlying factors of the subject. An extensive study by McGee (1979a) reviews the literature and shows that the reason for inconsistency and confusion concerning the structure of spatial ability is investigators' inconsistent naming of the factors. McGee (1979a) concludes that there are two main factors: *Spatial Visualization* (Vz) and *Spatial Orientation* (SO). Vz is the ability to imagine manipulating, rotating, twisting, or inverting objects without reference to one's self. This ability is measured by complex tests, such as Paper Folding (Ekstrom, French, Harman, and Dermen, 1976, as reported in Snow and Lohman, 1979). McGee explained the other important dimension, SO, elsewhere (McGee, 1979b) as "the comprehension of the agreement of elements within a visual stimulus pattern and the aptitude to remain unconfused by the changing orientation in which a spatial configuration may be presented" (p.893). In short, *Spatial Orientation* is perceived as one's ability to imagine the appearance of an object from different perspectives.

In another review, Lohman (1988) argues that there are three major spatial ability factors: *Spatial Visualization* (Vz), *Spatial Orientation* (SO), and *Speeded Rotation* (SR). He explains that Vz is the most general factor; however, it is difficult to identify because the tests that define it usually have high loadings on the *general intelligence*, or overall mental ability. One important characteristic of the tests that define the Vz is their complexity. Some require rotation, reflection, or folding complex figures, others require combining different figures, yet some others require multiple transformations. When defining the SO, Lohman (1988) agrees with McGee and adds that it is difficult to separate SO from Vz because both of these factors require considerable reasoning skill and subjects may solve items by mentally rotating them rather than moving an image of the self to the desired perspective. Lohman (1988) believes that SR factor is defined by the tests in which subjects are required to determine whether a given stimulus is a rotated version of a two dimensional target (i.e., game card) or is a rotated and reflected version of it. A quick answer is expected from the examinees when taking those kinds of tests.

As Hagarty and Waller (2005) stated, the most comprehensive review of factor analytic studies of spatial ability was conducted by John Carroll in 1993. Carroll (1993) analyzed more than 140 datasets and detected five major clusters: *Visualization* (Vz), *Spatial Relations* (SR), *Closure Speed* (CS), *Flexibility of Closure* (CF), and *Perceptual Speed* (P).

Carroll's (1993) definition of Vz factor does not differ from than that of other researchers cited above. *Spatial Relations* factor can be considered as another name for the *Speeded Rotation* factor defined by Lohman (1988) for three dimensional objects. CS factor concerns individual differences in ability to access spatial representations in long-term memory when incomplete or obscured cues to those representations are presented. The subjects are not told what to look for in a given representation. CF factor involves finding hidden patterns or figures in a bigger complex pattern when the subjects are informed about what to look for. CF factor is sometimes called *Field Independence* or *Disembedding* by other researchers (Velez, Silver, and Tremaine, 2005). Although Carroll (1993) informs that the CF factor exists, he admits the fact that "the psychometric evidence for the factor is somewhat ambiguous" (p. 338). P factor is characterized by the speed in finding a given configuration in a mess of distracting material. The task may include comparing pairs of items, locating a unique item in a group of identical items, or locating a visual pattern in an extended visual field. The factors detected by Carroll (1993) are shown in Figure 1.

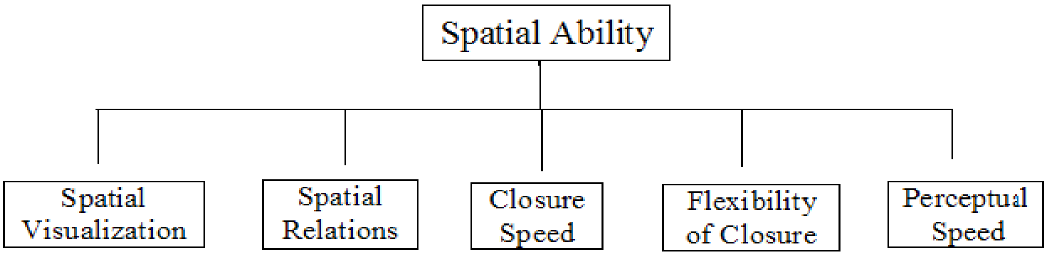


Figure 1 *Major factors of spatial ability based on Carroll's (1993) analysis*

Factor analytic studies on spatial ability have two main shortcomings. First, they do not provide the same results (i.e. detect the same underlying factors), which may lead to incorrect conclusions and confusion. To illustrate, while some of the studies clearly identify an SO factor, a comprehensive analysis of previous data sets by Carroll (1993) does not suggest such a factor. Second, those studies neglect dynamic spatial abilities and environmental abilities, which are considered as very important components of spatial ability domain (Hegarty and Waller, 2005).

Dynamic Spatial Ability (DSA) or *Spatiomeporal Ability* (SA) refers to judgments regarding a moving stimulus (Halpern, 2000). DSA is generally measured in the context of computerized tests (Colom, Contreas, Shih and Santacreu, 2003). The relative arrival time (which requires individuals to indicate which of the two moving objects will arrive first at a given target) and intercept judgment tasks are the markers of DSA (Law, Pallegrino and Hunt, 1993). *Environmental Ability* (EA) requires integrating spatial information about natural and artificial objects and surfaces in an individual's surroundings. These abilities are considered essential for way-finding and navigation (Allen, 1999; Bell and Saucier, 2004).

It can be concluded that spatial ability factors include the ones that Carroll (1993) suggests in addition to SO, DSA, and EA. As Hagerty and Waller (2005) argues, Carroll's (1993) failure in finding a separate SO factor does not mean that such a factor does not exist. It is possible that this ability has been poorly assessed. Theoretically, the critical distinction between Vz and SO is that Vz involves imagining the object's movement whereas SO involves imagining the change in one's perspective. Although there is a strong evidence regarding the existence of DSA and EA abilities to solve most of the spatial problems we encounter in our daily lives, some researchers noted that the mainstream literature ignore this fact (Allen, 1999; Allen, 2003; Bell and Saucier, 2004). To illustrate, environmental abilities are needed to find one's way between two known or unknown points. A comprehensive model of general spatial ability, including those overlooked components, is provided in Figure 2.

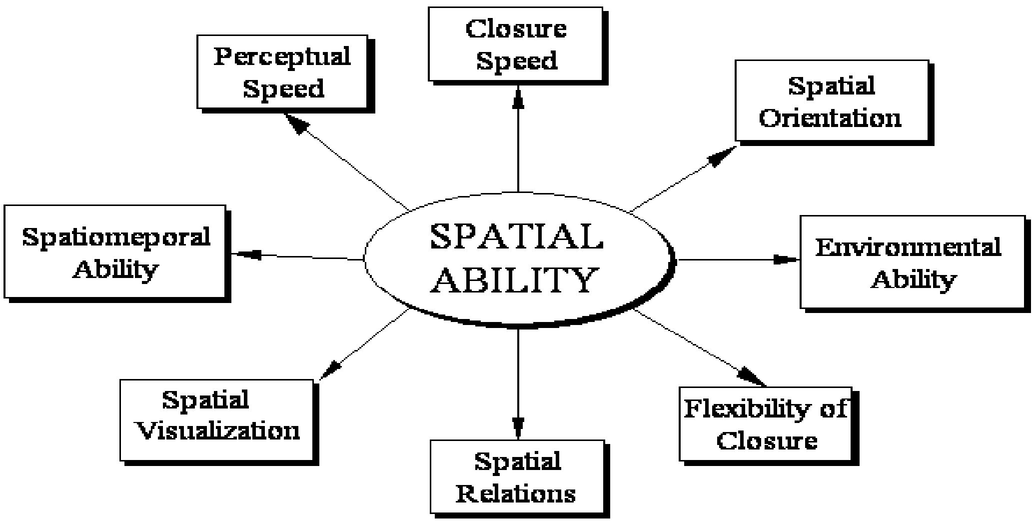
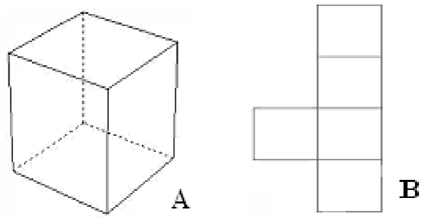
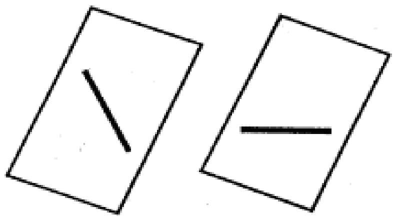


Figure 2 *Major factors of spatial ability.*

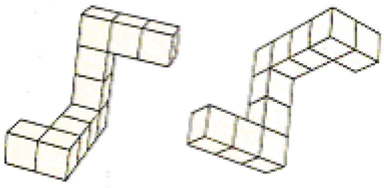
The debate on the nature and types of the spatial ability is still continuing. In a recent study, Allen (2003) groups spatial ability into three functional families: *object identification* (answering the "What is it?" question), *object localization* (answering the "Where is it?" question), and *traveller orientation* (answering the "Where am I?" question). According to the researcher, the "What is it?" family of abilities involves a stationary observer and stationary (usually movable or manipulable) objects; the "Where is it?" family involves the context of situations including either a stationary or mobile observer and mobile (mostly animate) objects; and the "Where am I?" family involves a mobile observer and a stationary world of environmental objects and surfaces. It seems that his work actually re-groups the factors in *Figure 2* under bigger clusters. *Figure 3* includes item samples for some of the major components of spatial ability.



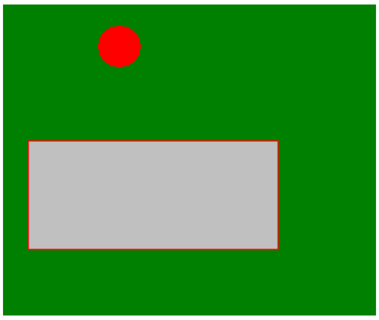
Spatial Visualization
Is Figure B part of Figure A?



Spatial Orientation [b]
Align a rod within these frames so that the rod is vertical.



Spatial Relations [1]
Is this pair of figures same or not?



Spatiotemporal Abilities

A falling red ball is obscured by a shaded rectangular area on the computer screen. Press any key when you expect it to be visible on other side of the shaded area.

Figure 3 *Examples of spatial ability test items.*

Development of Spatial Ability

[b] Adapted from Halpern, 2000

Development of spatial cognition which entails the ability to mentally represent spatial relations and to anticipate the course and outcome of transformations applied to those relations has long attracted the interest of behavioural scientists (Rosser, 1995). Writings of Piaget has guided the research on the developmental aspect of the phenomenon. His work suggested that children's spatial ability does not reach an adult level before age twelve (Piaget and Inhelder, 1967). Piaget and Inhelder (1967) defined two types of spatial ability when a child interacts with his/her environment. *Perceptual Spatial Ability*, the ability to perceive the spatial relationships between objects; and *Conceptual Spatial Ability*, the ability to build and manipulate a mental model of the environment. According to those researchers, children progress through three stages in the development of their cognitive spatial ability: preoperational stage, concrete operational stage, and formal operational stage.

Piaget and Inhelder (1967) indicated that children younger than six years old are in the *preoperational* stage of cognitive development. The internal model of children in this stage is egocentric; that is, they locate objects in their environment with respect to themselves. They understand limited topological spatial relationships, such as separation, proximity, and open/closed. The second stage is the *concrete operational* stage, which occurs when children are between seven to nine years old. In this stage they develop a cognitive map with a fixed frame of reference, which allows them to imagine a view and orientation outside their body. Children develop an understanding of more complex topological relations using an external frame of reference, such as order and enclosure, and they begin to develop projective relations, like before/behind, and left/right. The last stage of cognitive development in childhood is the *formal operational* stage, which begins around the age of 11. In this stage, children develop a coordinate frame of reference, where individual routes blend into a network of locations in fixed positions relative to each other. They develop an understanding of Euclidean spatial relations, such as estimating straight-line relative distances, and proportional reduction of scale (Piaget and Inhelder, 1967).

On the other hand, Huttenlocher and Newcombe (2000) suggest that spatial understanding develops earlier than proposed in Piaget's work, and believe that the stages of spatial development can be summarized as follows:

- Infants at the age of six months are able to use dead reckoning skills (e.g. keeping track of direction of a moving item by integrating distance traveled with changes in motion and heading) to understand the location of objects around them. This is an inborn ability to understand distances and people use it to navigate.
- Babies at 12 months are able to understand distance in a way that helps them find hidden stimuli.
- By 18 months, they are able to understand and navigate simple routes.
- Children are able to use distance information from landmarks to define locations, which seems to be related to the maturation of the brain, by they are two years old. Piaget had contended that this ability did not develop until ages nine or ten.
- They are able to use simple maps and models at three years old.
- Children continue to grow in spatial understanding and complete their mental development in spatial learning by the time they are nine or ten provided that

they are encouraged to use/play with maps and tools (Huttenlocher and Newcombe, 2000).

As indicated above, whereas there is a consensus on the idea that children's spatial ability is not as high as adolescents', there is a lack of agreement among the scientists about the process and steps of spatial development. Furthermore, research indicates that the development pattern of spatial ability for boys and girls are somewhat different from each other (Maccoby and Jacklin, 1974; Cohen, 1977; Glea and Kimura, 1993). The next part of the paper will look at this topic along with other issues regarding gender differences in spatial ability.

Gender Differences in Spatial Ability

Although it is accepted that there are differences between males and females in their spatial abilities, the nature and magnitude of that difference is another topic on which researchers disagree (Maccoby and Jacklin, 1974; Linn and Petersen, 1985; Voyer et al., 1995). Since most of the spatial ability tasks correlate strongly, researchers grouped those tasks under categories when studying the gender issue (Linn and Petersen, 1985; Voyer, et al., 1995). Those categories and the tasks that constitute them will be discussed below. Note that the components that are commonly accepted as showing reliable gender differences will be examined first. In addition, the size of any sex difference in spatial performance is reported using the statistical effect size, d (the mean standardized difference between scores of two groups; males and females) which can be calculated as follows:

$$d = \frac{\mu_{(big)} - \mu_{(small)}}{\sigma_{pooled}} \quad \text{where}$$

$\mu_{(big)}$ = bigger mean;
$\mu_{(small)}$ = smaller mean;
$\sigma_{(pooled)}$ = the square root of the average of the squared standard deviations.

An effect size of 1.0 describes a sex difference of 1 pooled standard deviation between the means. According to Cohen (1977), an effect size over .80 represents a 'large' effect.

Mental Rotation (MR)

Before going any further, it is necessary to remind that researchers have given different names to same (or very similar) components of spatial ability. When the topic is gender difference, many researchers (Kimura, 1999; Linn and Petersen, 1985; Voyer, et al., 1995) used *Mental Rotation* (MR) having a very close meaning to Carroll's Spatial Relations (SR) factors. The difference is that MR includes rotating a two or three dimensional object or figure, whereas SR requires imagination of an object in two or three dimensional space in relation to another object (Aszalos and Bako, 2004).

Vanderburg and Kuse's (1978) version of Mental Rotations Test (MRT), which is originally created by Shepard and Metzler (1971), is the most commonly used test to measure MR ability. This test involves questions that require subjects to decide whether novel three-dimensional objects are the same as a sample object regardless of their orientation. Results of meta-analyses (Linn and Petersen, 1985; Voyer, et al. 1995) showed that, although the amount of difference varies by the age of the group taking MR tests, males tend to outperform females on MR at any age starting with age 10, at which the earliest measurement of MR was possible. Voyer et al. (1995) calculated effect sizes between d=.56 ($p<.05$) and d = .019 (varies by tests). A study by Levine, Huttenlocher, Taylor and Langrock (1999) shows that there is a significant male advantage on mental rotation task by the age of 4.5.

While the object used in MR tasks differs as a result of a number of factors, such as complexity and dimensionality, overall task difficulty seems to be the primary determinant of the size of the difference. For instance, tasks including three-dimensional stimuli are commonly reported as showing a larger sex difference than the ones including two-dimensional stimuli (Linn and Petersen, 1985).

Spatial Perception

Linn and Petersen (1985) and Voyer and his colleagues (1995) perceive this component as the ability to determine spatial relationships with respect to the orientation of one's own body. A very similar definition is given for *Spatial Orientation* by McGee (1979b) as mentioned above. Rod and Frame Test (RFT) (shown in Table 1) and Piaget and Inhelder's (1956) Water Level Test, which involves the orientation of water line in a tilted glass, are the most commonly used tests to measure *Spatial Perception* skill. Voyer et al. (1995) reported male advantage with an effect size of .42 for the first test and .48 for the second one.

Kimura (1999) argues that these tests also measure *Field Independence* or *Flexibility of Closure* (CF) skill. He explains that the tilted frame and tilted glass serve as distracters from vertical and horizontal respectively. Individuals who can disregard these distractions perform better than the others. Voyer et al. (1995) state that the earliest age at which gender differences reported is 7 for the RFT, and 9 for the Water Level Test; on the other hand, Linn and Petersen (1985) point out that at age 4 girls outperform boys, but starting from age 5 boys get better scores than girls, and the difference gets statistically different at age 11.

Spatial Visualization

Tasks that have been grouped by Linn and Petersen (1985) and Voyer et al. (1995) as spatial visualization tests also show male advantage. Yet, the difference between males and females on those tests are much smaller and less reliable than those found in the *Multiple Rotation* and *Spatial Perception* groups. Among the most employed tests to measure spatial visualization tasks are Paper Form Board, which requires individuals to detect what an unfolded shape would look like when folded, and the Identical Blocks Test, in which participants should decide which block among a number of alternatives is the same as a sample block, given a variety of identifying features such as colours and numbers on the faces of the blocks. Voyer et al. (1995) inform that the difference before age 18 is not significant; however, the difference becomes significant ($p<.05$) with an effect size of .23 when the participants are over 18 years old.

Other Findings on Gender Difference

Literature includes studies focusing on gender differences in the other spatial ability domains as well, such as *Dynamic Spatial Abilities* (DSA) and *Environmental Abilities* (EA); however, the number of studies on DSA is not enough to allow reliable effect size estimates (Halpern and Collaer, 2005). Law, Pellegrino, and Hunt (1993) conducted an experiment to examine the gender difference in relative velocity and distance judgment tasks. Subjects observed two dynamic objects moving in different paths with different velocity values on the computer screen and asked to identify which object was moving faster. Tasks involving judgments about the speed or anticipated position of moving targets resulted in higher scores for males. Tests that assessed navigational (way-finding) ability by different tasks, such as using maps and three-dimensional environments, also found male superiority. To illustrate, Glea and Kimura (1993) concluded that, when learning a novel route through a map of a town, males showed faster learning and made fewer errors.

The literature has well established that males perform better than females on spatial tasks. Linn and Petersen (1985) suggest that females use less effective strategies than males, which result in a better male performance on spatial tasks. For instance, they observed that females tend to reflect more caution, double check their answers, and take more time when they are to answer test items. Linn and Petersen (1985) also noted that females find spatial tasks more difficult than males do.

There are many competing explanations for gender difference, but it is possible to put them into two main groups: (a) *biological factors*, (b) *socio-cultural factors*.

Biological Factors

Majority of the research explaining gender differences in terms of biological factors focuses on two main areas: hormones and brain maturation. Studies with hormonal abnormalities show that gonadal hormone levels are related to the development of spatial skills (Levy and Heller, 1992). For instance, females who have high androgen levels during prenatal development and early ages have higher spatial ability than others (Hampson, Rovelt and Altman, 1998), and males who have low androgen level at early ages have low spatial ability than normal males (Hier and Crowley, 1982; cited in Levine et al., 1999). Prenatal exposure to androgens is thought to be an important factor in the development of spatial ability.

The human brain is divided into two hemispheres; the left hemisphere underlies language and verbal skills and the right hemisphere underlies visual-spatial skills. It has been known for decades that the right hemisphere in fatal males is bigger and develops earlier than that of females (de Lacoste, Hovarth and Woodward, 1991), which is hypothesized to be related to the spatial skill advantage in males (Levine et al., 1999). In addition, Pakkenberg and Gundersen (1997) inform that males have 16% more neocortical neurons than females, which may result in more synaptic connections and contribute to cognitive differences.

Socio-cultural Environment

Socio-cultural environment includes issues like play, gender roles, social and parental expectations, and educational experiences that affect the development of a child's abilities. Voyer, Nolan, and Voyer (2000) observe that while most of the male-typical activities involve a high spatial content, female-typical activities do not. Childhood experiences are thought to have influence on the development of spatial ability (Saucier, McCreary, and Saxberg, 2002).

While gender differences in toy play appears at a very young age, it is not clear exactly when the difference in toy preferences appears. Some studies suggest that, as early as age 3, children prefer to play with toys deemed appropriate for their own gender (Green, Bigler, and Catherwood, 2004). On the other hand, other researchers, such as Jackllin, Mackoby, and Dick (1973), found evidence that gender differences in toy preferences exist in 1-year-old children. Most of the time boys play with toy vehicles and blocks, which involve spatial manipulations, while girls play with stuffed animals and dolls, which help the development of social skills (Etaugh and Liss, 1992; Levine et al. 1999; Voyer et al, 1995). It has been reported that preschool boys spend more time with their teachers than girls, and they play games with construction sets, toy vehicles, blocks, and legos; however, girls spend most of their time in dramatic play area and interact socially (i.e., verbally). This is also the case when those children spend time at home either with their parents or caregivers (Levine et al., 1999).

According to the social learning theory, operant conditioning of gender roles can play roles on toy preferences. The consequence of behaviour affects the likelihood of the recurrence of that behaviour: while favourable consequences increase the tendency to repeat the behaviour, adverse consequences decrease it (Mazur, 2005). Lytton and Romney (1991) reviewed more than 170 studies on parents' behaviour towards children and found that parents encourage girl-typical toy (e.g., with dolls) more in girls and boy-typical toys (e.g., with blocks) more in boys. After reviewing the literature on child toy preferences, Lippa (2002) concludes that "parents engage in *gender policing* when their children engage in cross-sex activities. Fathers tend to police more than mothers, and everyone polices boys more than girls" (p. 137). In this case, it could be expected that boys will have higher spatial ability than girls since they are encouraged to play with toys that require more spatial skills.

Besides the toy preference, typical play activities for boys are generally rough sports, such as football and ice-hockey requiring more spatial skills (especially targeting skill) than others like swimming and jogging (Kimura, 1999; Voyer et al., 2000). It is important to state that toy and play preferences are not thought to be only as a function of social experiences. A group of researchers propose that innate biological differences and the brain development also have influence on those issues (Alexander and Hines, 2002, cited in Green et al., 2004). Based on the previous studies on toy preferences and game types during early childhood, it is logical to claim that boys have more opportunity to develop their spatial ability than girls, which may –at least partially- help explaining the reason for the gender difference in spatial ability.

Another socio-cultural factor that may lead to gender differences in spatial ability is the differences in occupational choices. Some occupations requiring spatial ability are mostly preferred by males (e.g., pilot, engineer, surgeon, etc.) (Halpern, 2000). This may be caused by experience, social pressure, and educational opportunities. For instance, being canalized to play with certain kinds of toys and pressure from parents and teachers may result in an increase in spatial ability. Guay and McDaniel (1977) reported that "...among elementary school children, high mathematics achievers have greater spatial ability than low mathematics achievers." (p.214). Moreover, it is reported that there are gender differences favouring girls in verbal abilities and favouring boys in mathematical abilities (Maccoby and Jacklin, 1974).

It has been suggested that the nature of advanced topics in mathematics (geometry, topology, trigonometry, etc.) require spatial skills (Halpern, 2000). Similarly, Skolnick, Langbort, and Day (1982) argue that spatial ability plays an important role in children's understanding in mathematical and scientific concepts. Siemankowski and McKnight (1971) give examples that might be the reason for high correlation between spatial ability and success in science classes:

> Science students are constantly subjected to diagrams, usually of two dimensional representations of three dimensional models ... The need for three-dimensional conceptualization is necessary for the comprehension of wave energy transmission, chemical bonding, fields of force, structure of the atom, x-ray diffraction patterns, DNA, cell division, and countless other concepts and phenomena found in every branch of science (p. 56).

In general, boys have a higher spatial ability than girls which may be caused by biological and/or environmental factors. As a result of that difference, some occupations closely related to spatial ability have been male-dominated.

There is evidence that the difference between males and females in their spatial ability is changing. Feingold (1988) proposed that the gap between males and females in spatial ability has decreased as a result of an increase in spatial experience of females. However, Voyer et al. (1995) believes that, although the difference in mental rotation tends to increase, the difference in spatial perception tends to decrease for individuals born recently, which makes one think that various spatial tasks may be differentially sensitive to the effects of experience.

One of the increasingly popular ways to interpret gender differences in spatial performance is to consider that they arise from an interaction of biological and socio-cultural factors. Sherman's (1978) "bent twig" theory is a good example of that approach. This theory says that when choosing an activity, one of the many factors involved is an innate predisposition for the abilities required by that activity. This means that boys might tend to do some activities (i.e., playing with blocks) because of their inborn predisposition for spatial abilities. From this perspective we can argue that "boys generally have good spatial abilities from an early age and this guides their choice of activities, which in turn contributes to an increase in the magnitude of gender differences" (Voyer et al., 2000, pp.893). This explanation seems to help us understand the nature of the difference in spatial ability.

There have been many studies investigating the ways to improve spatial ability of individuals. For instance, Leng and Shaw's (1991) found that similar neural firings patterns occur when listening to music and performing spatial tasks; Rauscher, Shaw and Ky (1993) hypothesized that listening to certain types of complex music warms-up neural transmitters inside the cerebral cortex (region of the brain that is responsible for cognitive functions) and thereby improve spatial performance. Rauscher et al.'s (1993) experiments showed that listening to the first ten minutes of the Mozart's Sonata *K.448* resulted in significantly higher scores on college students' spatial-temporal ability (i.e., combining separate elements of an object into a single whole) for about fifteen minutes. Hundreds of similar studies have been conducted to investigate the effects of Mozart's music on spatial ability for different age groups (mostly with college students); however, the results of those studies remain controversial. Even replication studies suggested inconsistent findings (McKelvie and Low, 2002). On the other hand, research on the effect of music training on spatial ability development of preschool children has provided consistent results that music education increase spatial performance (Rauscher, 1996). To illustrate, Rauscher et al. (1997) conducted a two-year study that examined the effect of keyboard training on spatial ability of preschool children. They had four groups of preschool children whose age ranged from 36 to 57 months: first group took piano lessons and participated in singing sessions; remaining students were assigned to one of the three groups—Singing (participated in singing sessions), Computer (took computer lessons), and No Lessons. The result of the study indicated a significant ability increase only for the first group.

Conclusion

Spatial ability and its development in males and females have attracted the attention of researchers for a long time. Yet, as literature points out, there are many studies revealing contradicting results which make it difficult to have a comprehensive understanding of the subject (Newcombe and Learhmont, 2005; Halpern, 2000; Pallegrino and Hunt, 1991; Snow and Lohman, 1985). Although the number of underlying factors of spatial ability varies from study to study, most investigations have found significant differences between males and females in most of those factors, such as *Mental Rotation*, *Spatial Relations* (Voyer et al., 1995, Linn and Petersen, 1985), and *Environmental Ability* (Glea and Kimura (1993).

As discussed in the current study spatial ability is a comprehensive construct which have an effect on one's everyday life, school achievement, and success in certain types of jobs. Efforts to comprehend the nature and development of spatial ability have led to two distinctive underlying dynamics: biological and socio-cultural factors. Examination of the factors like neural system, genes, toy preferences, teacher and parent behaviours, and job preferences, and the interactions between them, will help researchers find more efficient ways to increase spatial ability and explore better means of delivering instruction to children.

As a result, achievement gap between boys and girls on mathematics and science courses might be diminished. Along the same lines it might be possible to increase the girls' enrolment rate in currently male-dominated science, mathematics and technology related courses and departments when they go to higher education institutions.

References

Alexander, G. M., & Hines, M. (2002). Sex differences in response to children's toys in nonhuman primates (Cercopithecus aethiops sabaeus). *Evolution and Human Behavior, 23*, 467-479.

Allen, G. L. (1999). Cognitive abilities in the service of wayfinding: A functional approach. *Professional Geographer*, *51*(4), 554-561.

Allen, G. L. (2003). Functional families of spatial abilities: poor relations and rich prospects. *International Journal of Testing, 3*(3), 251-262.

Anderson, J. R. (1990). *Cognitive psychology and its implications* (3rd Ed.). San Francisco, CA: Freeman.

Aszalos, L., & Bako, M. (2004). Paper presented at 6th International Conference on Applied Informatics, Eger, Hungary.

Bell, S., & Saucer, D. (2004). Relationship among environmental pointing accuracy, mental rotation, sex, and hormones. *Environment and Behavior, 36*(2), 251-265

Carroll, J.B. (1993). *Human cognitive abilities: a survey of factor analytic studies*. Cambridge: Cambridge University Press.

Cohen, J. (1977). *Statistical power analysis for the behavioral sciences*. San Diego, CA: Academic Press.

Colom, R., Contreas, M.J., Shih, P.C., & Santecrau (2003). The assessment of spatial ability through a single computerized test. *European Journal of Psychological Assessment, 19*(2), 92-100.

Cooper, L. A., & Mumaw, R. J. (1985). *Spatial aptitude*. In R. F. Dillman (Ed.). Individual differences in cognition (2nd. Ed., pp.67-94). New York, NY: Academic Press.

Daniel L. Shea, D.L., Lubinski, D., & Benbow, C. P. (2001). Importance of assessing spatial ability in intellectually talented young adolescents: a 20-year longitudinal study. *Journal of Educational Psychology, 93* (3), 604-614.

de Lacoste, M. C, Horvath, D. S., & Woodward, D. J. (1991). Possible sex differences in the developing human fetal brain. *Journal of Clinical and Experimental Neuropsychology, 13,* 831—846.

Ekstrom, R. B., French, J. W., Harman, H. H., & Dermen, D. (1976). *Kit of factor referenced cognitive tests*. Princeton, NJ: Educational Testing Services.

Glea, L. A. (1993). Sex differences in route-learning. *Personality & Individual Differences, 14*(1), 53-65.

Green, V. A., Bigler, R. S., & Catherwood, D. (2004). The variability and flexibility of gender-typed toy play: a close look at children's behavioral responses to counterstereotypic models. *Sex Roles, 51*(7-8), 371-386.

Guay, R. & McDaniel, E. (1977). The relationship between mathematics achievement and spatial abilities among elementary school children. *Journal for Research in Mathematics Education 8*(3), 211-215.

Halpern (2000). *Sex differences in cognitive abilities* (3rd Ed.). Mahwah, NJ: Lawrence Erlbaum Associates.

Hampson, E., Rovet, J. F., & Airman, D. (1998). Spatial reasoning in children with congenital adrenal hyperplasia due to 21-hydroxylase deficiency. *Developmental Neuropsychology, 14,* 299-320.

Hegarty, M. & Waller, D. (2005). *Individual differences in spatial abilities*. In P. Shah & A. Miyake (Eds). The Cambridge handbook of visuospatial thinking. New York, NY: Cambdridge University Press.

Hier, D. B., & Crowley, W. F. (1982). Spatial ability in androgen-deficient men. *New England Journal of Medicine, 306,* 1202-1205.

Huttenlocher, J., Newcombe, N., & Vasilyeva, M. (1999). Spatial scaling in young children. *Psychological Sciences, 10*(5), 393-398.

Jacklin, C. N., Maccoby, E. E., & Dick, A. E. (1973). Barrier behavior and toy preferences: sex differences (and their absence) in the year old child. *Child Development, 44*, 196-200.

Kimura, D. (1999). *Sex and cognition*. Cambridge, MA: The MIT Press.

Law, D. J Pellegrino, J.., W., & Hunt, E. B. (1993). Comparing the tortoise and the hare: gender differences and experience in dynamic spatial reasoning. *Psychological Science, 4,* 35–40.

Leng, X., & Shaw, G. L. (1991). Toward a neural theory of higher brain function using music as a window. *Concepts in neuroscience, 2*, 229-258.

Lewine, S. C., Huttenlocher, J., Taylor, A., & Langrock, A. (1999). Early sex differences in spatial skill. *Developmental Psychology, 35*(4), 940-949.

Linn, M., & Petersen, A.C., 1985, Emergence and characterization of sex differences in spatial ability: A meta-analysis, *Child Development, 56*, 1479-1498.

Lohman, D. F. (1988). *Spatial abilities as traits, processes, and knowledge*. In R. J. Stenverg (Ed.). Advences in the psychology of human intelligence (pp. 181-248). Hillside, NJ: Erlbaum.

Lohman, D. F. (1993). *Spatial ability and g*. Paper presented at the first Spearman Seminar, University of Plymouth, England.

Lytton, H., Romney, D. M. (1991). Parents' differential socialization of boys and girls: A meta-analysis. *Psychological Bulletin 109*, 267-296.

Maccoby, E. E., & Jacklin, C. N. (1974). *The psychology of sex differences*. Stanford, CA: Stanford University Press.

Mazur, J. E. (2005). *Learning and behavior*. New Jersey: Prentice Hall.

McGee, M. G. (1979a). *Human spatial abilities: sources of sex differences*. New York, NY: Preager.

McGee, M. G. (1979b). Human spatial abilities: psychometric studies and environmental, genetic, hormonal, and influences. *Psychological Bulletin, 86*(5), 889-918.

McKelvie, P., & Low, J. (2002). Listening to Mozart does not improve children's spatial ability: final curtains for the Mozart effect. *British Journal of Developmental Psychology, 20*, 241-258.

Newcombe, N.S. & Learhmont, A. E. (2005). *Development of spatial competence*. In P. Shah & A. Miyake (Eds). The Cambridge handbook of visuospatial thinking (pp. 213-256). New York, NY: Cambdridge University Press.

Oliviera, T (2004). Dynamic spatial ability: an exploratory analysis and a confirmatory study. International *Journal of Aviation Psychology, 14*(1), 19-38.

Pallegrino, J. W. & Hunt, E. B. (1991). *Cognitive models for understanding and assessing spatial abilities*. In H. A. H. Rowe (Ed.). Intelligence: reconceptualization and measurement. Hillside, NJ: Lawrence Erlbaum Associates.

Piaget, J., Inhelder, B. (1967). *The child's conception of space*. New York, NY: Norton.

Rauscher, F. H., Shaw, G. L., Levine, L. J., Wright, E. L., Dennis, W. R., & Newcomb, R. L. (1997). Music training causes long-term enhancement of preschool children's spatial-temporal reasoning. *Neurological Research, 19*, 2-8.

Rauscher, F. H. (1996). *A cognitive basis for the facilitation of spatial-temporal cognition through music instruction*. In V. Brummet (Ed). Ithaca conference '96- music as intelligence: a sourcebook (pp. 31-44).

Rauscher, F. H., Shaw, G. L., & Ky, K. N. (1993). Music and spatial task performance. *Nature, 385*, 611

Rosser, R. (1994). The developmental course of spatial cognition: evidence for domain multidimensionality. *Child Study Journal, 24*(4), 255-280.

Saucier, D. M., McCreary, D. R., & Saxberg, . K. (2002J). Does gender role socialization mediate sex differences in mental rotations? *Personality & Individual differences, 32*(6), 1101-1111.

Siemankowski, G. & MacKnight, F. (1971). Spatial cognition: success prognosticator in college science courses. *Journal of College Science Teaching 1*(1), 56-59.

Sherman, J. A. (1978). *Sex-related cognitive differences.* Springfield, IL: Charles C. Thomas.

Snow, R. E., & Lohman, D. F. (1989). *Implications of cognitive psychology for educational measurement.* In R.L. Linn (Ed). Educational Measurement (3rd Ed., pp.263-331). New York, NY: Macmillan.

Skolnick, J., Langbort, C., & Day, L. (1982). *How to Encourage girls in math and science.* Englewood Cliffs, NJ: Prentice Hall.

Velez, M., Silver, D., & Tremaine, M. (2005). Understanding visualization through spatial ability differences. Paper presented at the IEEE Visualization 2005 Conference, Minneapolis, MN.

Voyer, D., Nolan, C., & Voyer, S. (2000). The relation between experience and spatial performance in men and women. *Sex Roles, 43*(11-12), 891-915.

Voyer, D., Voyer, S., & Bryden, M. P. (1995). Magnitude of sex differences in spatial abilities: a meta-analysis and consideration of critical variables. *Psychological Bulletin, 117*, 250-270.