European Journal of Physical Education and Sport Science
ISSN: 2501 - 1235
ISSN-L: 2501 - 1235
Available on-line at: www.oapub.org/edu

doi: 10.5281/zenodo.3386066 Volume 4 | Issue 4 | 2018

SPATIAL ABILITIES: A LITERATURE REVIEW

Mohammad Tanweer
Ph.D. Scholar, Department of Teachers' Training
and Non-formal Education,
Institute of Advance Studies in Education,
Jamia Millia Islamia,
New Delhi, India

Abstract:
This paper is an attempt to summarize the researches on spatial ability in order to understand the viewpoints of different psychological approaches viz psychometric approach, developmental approach, differential approach and information processing approach and their contributions to the knowledge of spatial ability.

Keywords: individual skills, spatial abilities, literature review

1. Introduction

The spatial ability is one of the most important individual skills, which helps one to comprehend many aspects of daily and academic life, and is particularly crucial in understanding scientific concepts and has it been research extensively. In 1880, Sir Francis Galton, discussed about certain mental pictures (mental imagery) in his reports. Since then, spatial ability has been defined in different ways, for example, discussion of its various constituents and methods through which it can be measured. Now, spatial ability has become a significant aspect in the research of other disciplines as well.

2. Tracing the History

No publication focusing on spatial ability research was available until the beginning of 1920s. Initially, research between 1880 and 1940 defined spatial ability as a unique capacity. It was not linked to general intelligence. Works of Kelley (1928), Thorndike (1921), Thurstone (1938) and El Koussy (1935) acknowledged spatial ability as a distinct factor which differed from Spearman's (1927) general intelligence factor. Initially, the researches were primarily based on a psychometrics (Pellegrino, Alderton & Shute, 1984) utilizing "*a set of statistical techniques (factor analysis) developed to determine the*

number and nature of underlying intelligence or personality factors that accounts for a given set of performance measures" (Cooper & Mumaw, 1985, pg.68).

Spatial ability as a factor of intelligence got highlighted and gained importance during the World War II when a large-scale testing of spatial ability was run in the Air Forces and Army (Guilford & Lacy, 1947; Guilford & Zimmerman, 1947a). From 1940-1960, researchers focused on what spatial ability consists of, lending to a single space factor. Subsequent research established that spatial ability is not comprised of single space factor. This period of research extended the knowledge of spatial ability and various factors comprising it.

Conversely, confusion among the theorists and researchers prevailed (D'Oliviera, 2004; Lohman 1979a). It largely happened due to variations in the names of factors, number of factors, and their definitions, which further led to variations in their technical implementation during factor analysis. In addition, there were usage of different types and numbers for spatial ability tests. (Cooper & Mumaw, 1985). Following this period, it was accepted that spatial ability is not a single separate capacity. Thus, several tests of spatial ability emerged after this time period. (Smith & Eliot, 1983).

The period between 1960 and 1980 witnessed materialization of research on spatial ability. Along with the psychometric studies, the developmental studies and differential studies also started gaining importance. Witkin (1949, 1950) and Gardner (1953, 1957) worked in the psychometric area. Their work helped in understanding spatial ability from a cognitive point of view, such as through learning styles. On the other hand, developmental studies examined the progression/changes in spatial ability as a child grows into an adult. The works of Piaget and Inhelder (1967, 1971) have made the study of developmental aspect of spatial ability further interesting. Differential research, on the other hand, focusses on differences in spatial ability (e.g.: through gender). It relates to various other attributes. For example, Maccoby and Jackline (1974) works on spatial ability act as a primary reference point for the differential research point of view.

Recently, information processing has become an important factor in understanding spatial ability. Thus, various information-processing models were developed to describe spatial ability theoretically. The present day's research largely focuses technology's influence on the measurement, examination, and upgrading of spatial ability.

From this century worth of research, it has now become clear that spatial ability comprises complex cognitive abilities with several unanswered questions.

3. Psychometric Research and Spatial Ability

Initially, difficulties were faced by researchers in distinguishing factors of spatial ability from that of general intelligence because several spatial factors depended heavily on the latter (such as, spatial visualization tests). Classically, two varying point of views have been used when studying intelligence: one, hierarchically and two, taxonmetrically

(Gustafsson, 1988). Upon factor analysis of mental tests, the first extracted factor corresponds to g. When g is removed, the tests could be assigned in two collections: the spatial-mechanical-practical (k: m factor) and the verbal-numerical (v: ed factor). Upon administering enough tests, they can be further divided into subgroups comprising of minor factors, the likes of spatial and manual, verbal, and numerical.

Systematic empirical work is the latest advancements in this field. The best-known contemporary factor analysis survey is by Carroll (1993) due to its extensive inclusion of datasets Carroll ascertained three hierarchical layers of cognitive abilities: the narrow, broad, and general layers. Radex theories are typically taxonomic (rather than hierarchical). Early radex theories are credited to Guttmann (1954).

3.1 Recognizing the Spatial Factor

The first ever-published research about spatial ability is Thorndike's work. In his work, 'mechanical intelligence' is "*ability to visualize relationships among objects and understand how physical world worked*." has set a base on which future research on spatial ability would follow.

Later, El Koussy (1935) and Kelley (1928) challenged the verbal-based meaning of intelligence (Burnett & Lane, 1980; Miller & Bertoline, 1991). El Koussy analyzed spatial intelligence and developed methods for measuring spatial ability. He found evidence related to existence to factor K. The K-factor denotes the ability to acquire and utilize visual spatial imagery. Kelley also believed that handling of spatial relation was another distinct factor within spatial ability.

In the same manner, Thurstone (1938) examined key mental abilities. He developed and elaborated the 'space' factor. It can be defined as functioning mentally on visuospatial images. According to his theory, intelligence rather than made of a single factor is made of several mental factors. These are proposed and elaborated in his 'Multiple Factors Theory.' The theory lists seven basic mental abilities: associative memories, perceptual speed, number facility, reasoning, verbal comprehension, spatial visualization, and word fluency. This theory formed the basis of intelligence tests that provided complete details of individual performance by analyzing several ability scores, instead of single score.

3.2 Multiple Space Factors

According to Thurstone (1950), there are three primary spatial factors enclosed in spatial ability. Literature published later proposed more descriptive terms (Smith, 1964) for the three primary factors proposed by Thurstone earlier.

- *Mental Rotation (S1):* Ability of differentiating orientation or angles.
- *Spatial Visualization (S2):* Ability of recognizing components of an object when they are displaced or moving away from an original position.
- *Spatial Recognition (S3):* Ability of using body orientation to relate to questions regarding spatial orientation.

After Thurstone, researchers made to attempt to list and define factors comprising spatial ability. However, there existed little coordination or relation

between them. This lack of unanimity amongst the researchers with respect to factors of spatial ability limited the research in the field. D'Oliviera (2004) acknowledged the conflicting area (areas of disagreement) in the factors proposed by different researchers, which include:

- Definitions of spatial ability; different researchers defined spatial ability differently.
- Number of factors comprising spatial ability.
- Names of the factors; variations were seen in naming the factors. Factors were named differently by various researchers.
- The tests used to measure each factor differed amongst the researchers.

Due to the recent developments in the research of spatial ability, two additional factors of spatial ability have been proposed.

- *Hypothetical imagery factor:* This is the outcome of Carroll's research work. It was defined by Carroll as "*the ability to form inner mental representations/images of visual patterns & using such representations/images in solving spatial problems (p.363).*" According to Burton and Fogarty (2002), who tried to find out if, it existed at all, this factor was found to relevant when testing spatial ability in relation to something apart from the everyday imagery. In fact, they recommended further research in this area to get more clarity from the studies.
- *Dynamic Spatial ability:* This term was given by Pellegrino and Hunt (1989, 1991) and first studied by Hunt, Pellegrino, Farr, Frick, and Alderton (1988). According to D'Oliviera (2004), it is the "*ability to deal with moving elements and relative motion*" (p.20). This interpretation by D'Oliviera was alternative way of viewing spatial ability, from static to dynamic quality. He also acknowledged that it was lack of valid tests that led to emergence of dynamic factors for measuring spatial ability. Several other researchers have later conducted studies on dynamic spatial ability as well (Anglin, Towers, & Moore, 1997; Contreras, Colom, Santacreu, & Hernandez, 2003; Kyllonen & Chaiken, 2003; Contreras, Colom, Alava, Shih, & Santacreu, 2001; Law, Pellegrino, & Hunt, 1993; McCuistion, 1989; Pellergino, Hunt, Farr & Abate, 1987; Saccuzzo, Craig, Larson, & Johnson, 1996).

4. Developmental Research and Spatial Ability

The role of developmental research is answer 'how' and 'when' spatial ability develops during the development of a child. This research primarily focusses on issues related to age i.e. the pattern of development of spatial ability with age. In addition, it involves neurological factors such as the hemispherical specialization. Piaget and Inhelder (1971) stated that as child matures, the spatial ability develops. This development of spatial ability happens in three phases.

1) *Topological Space stage:* In this, children acquire 2D skills and learn relationship of objects to the other.
2) *Projective Space stage:* In this, children learn to operate with 3D objects. Children learn about appearance of the object from different angles. This represents child's

orientation skills. They also learn how the objects look on rotation. This represents their rotational skills.

3) *Transition from Projective to Euclidean Space stage:* This is the third stage wherein a child switch between 2D and 3D objects. Here, individual learns the concept of parallelism, proportion, area, volume, and distance.

Some studies focused on differences in spatial ability at various age levels (Battista, 1990; Burnett, Lane, & Dratt, 1979; Fennema & Tartre, 1985; Lohman & Kyllonen, 1983; Salthouse, Babcock, Palmon, Mitchell, & Skovronek, 1990; Salthouse, 1987; Vandenberg, 1975). Other types of studies focused on ages at which particular aspect of spatial ability seem most apparent. (Linn & Petersen, 1986; Geiringer & Hyde, 1976; Salthouse & Mitchell, 1990; Piaget & Inhelder, 1967, 1971; Smith & Schroeder, 1979, Tartre, 1990; Maccoby & Jacklin, 1974; Vandenberg & Kruse, 1978). Several other studies focused on spatial ability over time. (Brinkman, 1966; Bishop, 1978; Coleman & Gotch, 1998; Clements, Battista, Swaminathan, & Sarama 1997; Dodwell, 1963; Salthouse et al., 1990).

As a child grows to become an adult, spatial ability also improves (Flanery & Balling, 1979; Orde, 1996). However, it is also seen that spatial ability declines after one reach adulthood (Macnab & Johnstone, 1990; Lawton, 1994; Pak, 2001). Skill for determining horizontal or vertical dimension does not develop until around the age of 9 years (Olson, 1975). Studies found that spatial ability develops differently in different sexes. It favors male at pre-pubertal ages (Vederhus & Krekling, 1996; Linn & Petersen, 1986), more precisely at the age of 7 or 8 years (Glasmer & Turner, 1995). Differences remain unchanged till the age of 18 years (Johnson & Meade, 1987).

Researchers focus on understanding brain physiology and its relation with spatial ability (Battista, 1990; Flanery & Balling, 1979; Hiscock, Inch, Iaraelian, & Hiscock-Kalil, 1995; Harris, 1979; Rilea, Roskos-Ewolden, & Bolen, 2004; Lowery & Knrik, 1982-83). It has been proved that an individual whose right hemisphere of the brain is dominant, they are able to perform better at spatial problems (McGee, 1976). Evidently, in the males, right side of the brain is dominant and hence their spatial ability develops more rapidly (Harris, 1978). Hence, hemispherical specialization has been observed in both the developmental perspectives as well as its differential development across sexes. Hemispherical specialization is a contributory factor when one tries to explain differences in spatial ability across sexes.

5. Differential Research and Spatial Ability

The literature dealing with differential development of spatial ability across sexes is considerably vast. It is one of favorite topics in the research of spatial ability. Normally, males outperform females in spatial tasks, mathematical reasoning, spatial perception, and targeting abilities. However, females outperform males in verbal fluency, memory, certain motor skills, and perceptual speed (Kimura, 1996). In addition, there are studies that indicate a decreasing trend of differences across genders or in some cases do not exist at all (Brownlow. 2001; Caplan, MacPherson, & Tobin, 1986; Fennema & Sherman,

1977; Jagacinski & Lebold, 1981; Hyde, 1981; Linn & Hyde, 1989; Lord & Garrison, 1998; Lohman, 1994; Michaelides, 2003; Smith & Litman, 1979).

Some researchers conclude spatial ability favoring the males irrespective of regions, ethnic group, classes, ages and other conceivable demographic factors (Eals & Silverman, 1994, p. 94). One can observe men's high performance when they are doing tasks related to mental rotation. Lesser differences were found between males and females with respect to case of orientation and no differences were seen in case of visualization (Harris, 1978; Stumpf, 1983; Linn & Petersen, 1986;). According to researchers, sex-based differences in spatial ability appear only after puberty. They further say maturation affects spatial development. For example, late maturation is linked with high spatial ability (Nyborg, 1983).

Same studies also emphasized that hormonal effect on spatial ability. Estrogen affects negatively whereas, testosterone has a non-linear effect on spatial ability (Alderton, 1989; McGinley, Pichardo, Voyer, Gatir, & Bryden, 1991; Kimura, 1996; Harris, 1978; Moffat & Hampson, 1996; McGee, 1979a; Nyborg, 1983). These studies have also pointed out that hormones are the main reasons for emergence of sex-based differences in spatial ability while others focus on real-time effect. According to several researchers, biological factors are responsible for sex-based differences in spatial ability (Bock & Vanderberg, 1968). Many studies indicate that spatial ability has a heritable component (Vanderberg1975, 1969; Vanderberg, Stafford and Brown, 1968). According to McGee (1979a), spatial ability is more inheritable than verbal ability.

Biological explanations for differences in spatial ability based on sexes emphasize the impact of hormones (Fruchter,1954; Newcombe, Bandura, & Taylor, 1983; Gardner, Jackson & Messick,1960, Nyborg, 1983), recessive X-linked gene (Bock and Kolakowski, 1983; Walker, Krasnoff, & Peaco, 1981; Vandenberg & Kruse, 1979; Stafford, 1961) and roles of males and females according to evolutionary theory (Silverman & Eals, 1992; Eals & Silverman,1994)

Amongst various illustrated biological theories, the recessive X-linked gene theory is the primary focus. However, article of Boles (1980), through reanalysis reputed this theory. He stated that most studies, which show evidence supporting the theory, were based on small samples. The size of the samples made it less acceptable a fact. In addition, the statistical results yielded through such samples were insignificant. The articles that explained the theory on the basis of X-linked recessive gene make the entire biological explanation questionable.

Like studies based on biological explanation, several other groups of researchers devoted their work to explain the role of environment in the development of differences in sexes. According to this group, following environmental factors are source of differences in spatial ability:

- Cultural (Berry, 1971; Belz & Geary, 1984; Mann, Sasanuma, Masaki, & Sakuma, 1990)
- Social (Belz & Geary, 1984)
- Sex roles and stereotypes (Nash 1975; Tracy, 1990)
- Developmental (Tracy, 1990)

- Educational (Bishop, 1989; Ballista, 1981; Conner, Serbin, & Schackman, 1977; Harris, 1978)

According to Sherman (1967), gender-based differences in spatial ability are the result of varied experiences. He believed that environment plays an important role in development of spatial ability. Several others agreed his viewpoint.

Many of these environmental factors that affect spatial ability are straight forward (i.e. they are clearly manifested). Furthermore, many educational factors are believed to impact spatial ability development. According to some researches, problems solving skills (Clements & Battista, 1992; Kyllonen, 1981; Hall & Obenauf, 1979; Kyllonen, Woltz, & Lehman, 1981; Lohman, 1987; Misery, Wingersky, Irvine, & Denn, 1990); mathematical background (Aihen, 1971, Brendrel,1981; Brown & Wheatley, 1989; Fennema & Sherman, 1978; Conner & Serbin, 1985; Friedman,1995; Humphreys. Lubinski, & Yao, 1993; Mckee, 1983; Landau, 1984; Michaelides, 2002; Pearson & Ferguson 1989; Moses, 1977; Wheatley, Brown & Solano, 1994); mathematical achievements and musical background (Heitland, 2000a, 2000b; Hartland, 1978; Robichaux & Guarino, 2000; Mason, 1986a) are potential roots for the development of spatial ability and there for the reason for sex based differences in spatial ability.

There are several researchers who instead of believing only one or the other (i.e. gender or environment), acknowledge that both biological and environment factors cause sex-based difference (Allen, 1974; Brosnan, 1998; Casey, Nuttall & Pezaris, 1999). As stated by Vanderberg, Stafford, and Brown (1963): "*It is time for psychologists to stop ignoring either source of variation (biological or environmental) and proceed with full recognition that two are highly interdependent*" (p. 153).

6. Information Processing Research and Spatial Ability

The objective of this approach is to understand the processes, speed, and order of the cognition. Many researchers working in this area observed the efficiency in spatial processing along with the influences on developing of spatial ability. According to several studies, efficiency and speed in transformation and performance of mental tasks, showcases a degree of diversity in spatial skills (Carpenter & Just, 1986; Metzler, 1973; Lohman 1979b; Mumaw & Pellegrino, 1984; Pelligeriro & Alderton, 1984; Salthouse et. al., 1990; Poltrock & Agnoli, 1986; Shepard & Melzler 1988). Studies have surveyed strategies for problem-solving related to spatial ability (Cooper & Mumaw, 1985; Lohman & Kyllonen, 1983; Kyllonen, Lohman, & Woltz, 1984; Gages, 1994; Moody, 1998). It was found that individuals with high spatial ability have wide range of techniques and are better in determining the appropriate time to use particular strategy. Differential studies have also been looked through an information processing perspective (Lohman, 1984).

7. Conclusion

Every research perspective has added significantly to understanding about spatial ability. Psychometric studies are contributory studies in describing spatial ability while developmental studies have traced the development and transition of spatial ability with age. Differential studies highlight the differences in spatial ability based on sexes. Lastly, information-processing literature focused on strategies chosen by individual and the way they are processed.

References

Alderton, D. L. (1989, March). The fleeting nature of sex differences in spatial ability. Paper presented at the annual meeting of the American Educational Research Association, San Francisco, CA.

Allen, M. J. (1974). Sex differences in spatial problem-solving styles. Perceptual and Motor Skills, 39, 843-846.

Anglin, G., Towers, R., & Moore, K. (1997). The effect of dynamic and static visuals on the recall and comprehension of information using computer- based instruction. Journal of Visual Literacy, 17(2), 25-37.

Battista, M. T. (1990). Spatial visualization and gender differences in high school geometry. Journal for Research in Mathematics Education, 21(1), 47-60.

Belz, H. F., & Geary, D. C. (1984). Father's occupation and social background: Relation to SAT scores. American Educational Research Journal, 21(2), 473-478.

Berry, J. W. (1971). Ecological and cultural factors in spatial perceptual development. Canadian Journal of Behavioral Science, 3(4), 324-336.

Bishop, J. E. (1978). Developing students' spatial ability. Science Teacher, 45(8), 20-23.

Bock, R. D., & Kolakowski, D. (1973). Further evidence of sex-linked major-gene influence on human spatial visualization ability. American Journal of Human Genetics, 24, 1-14.

Bock, R. D., & Vandenberg, S. G. (1968). Components of heritable variation in mental test scores. In S. G. Vandenberg (Ed.), Progress in human behavior genetics: Recent reports on genetic syndromes, twin studies, and statistical advances (pp. 233-260). Baltimore: John Hopkins Press.

Bodner, G. M. & McMillan, T. L. B. (1986). Cognitive restructuring as an early stage in problem solving. Journal of Research in Science Teaching, 23, 727-737.

Boles, D. B. (1980). X-linkage of spatial ability: A critical review. Child Development, 51, 625-635.

Brinkmann, E.H. (1966). Programmed instruction as a technique for improving spatial visualization. *Journal of Applied Psychology, 50* (2), 179-184.

Brosnan, M. J. (1998). Spatial ability in children's play with Lego blocks. Perceptual and Motor Skills, 87, 19-28.

Brownlow, S. (2001). How gender and college chemistry experience influence mental rotation ability. Paper presented at the Annual Meeting of the Southeastern Psychological Association, Atlanta, GA.

Burnett, S. A., & Lane, D. M. (1980). Effects of academic instruction on spatial visualization. Intelligence, 4, 233-242.

Burnett, S. A., & Lane, D. M. (1980). Effects of academic instruction on spatial visualization. Intelligence, 4, 233-242.

Burnett, S. A., Lane, D. M., & Dratt, L. M. (1979). Spatial visualization and sex differences in quantitative ability. Intelligence, 3, 345-354.

Burton, L. J., & Fogarty, G. J. (2002). The factor structure of visual imagery and spatial abilities. Intelligence, 31, 289-318.

Caplan, P. J., MacPherson, G. M., & Tobin, P. (1985). Do sex-related differences in spatial abilities exist? A multilevel critique with new data. American Psychologist, 40, 786-799.

Caplan, P. J., MacPherson, G. M., & Tobin, P. (1986). The magnified molehill and the misplaced focus: Sex-related differences in spatial ability revisited. American Psychologist, 41, 1016-1018.

Carpenter, P. A., & Just, M. A. (1986). Spatial ability: An information processing approach to psychometrics. In R. J. Sternberg (Ed.), Advances in the psychology of human intelligence (Vol. 3, pp. 221-253). Hillsdale, NJ: Lawrence Erlbaum Associates.

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

Casey, M. B., Nuttall, R. L., & Pezaris, E. (1999). Evidence in support of a model that predicts how biological and environmental factors interact to influence spatial skills. Developmental Psychology, 35(5), 1237-1247.

Clements, D. H., & Battista, M. T. (1992). Geometry and spatial reasoning. In D. Grouws (Ed.), Handbook of research on mathematics teaching and learning (pp. 420-464). New York: Simon and Schuster Macmillan.

Clements, D. H., Battista, M. T., Sarama J., & Swaminathan, S. (1997). Development of students' spatial thinking in a unit on geometric motions and area. The Elementary School Journal, 98(2), 171-186.

Coleman, S. L., & Gotch, A. J. (1998). Spatial Perception Skills of Chemistry Students. Journal of Chemical Education, 75(2), 206-209.

Conner, J. M., & Serbin, L. A. (1985). Visual-spatial skill: Is it important for mathematics? Can it be taught? In S. F. Chipman, L. R. Brush, & D. M. Wilson (Eds.), Women and mathematics: Balancing the equation (pp. 151- 174). New Jersey: Lawrence Erlbaum Associates.

Conner, J. M., Serbin, L. A., & Schackman, M. (1977). Sex differences in children's response to training on a visual-spatial test. Développemental Psychology, 13(3), 293-294.

Contreras, M. J., Colom, R. Hernandez, J. M., & Santacreu, J. (2003). Is static spatial performance distinguishable from dynamic spatial performance? A latent-variable analysis. The *Journal of General Psychology, 130*, 277-288.

Cooper, L. A. (1980). Spatial information processing: Strategies for research. In R. Snow, P. A. Federico, & W. E. Montague (Eds.), Aptitudes, learning, and instruction: Cognitive process analysis (pp. 149-176). Hillsdale, NJ: Lawrence Erlbaum Associates.

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

D'Oliveira, T. C. (2004). Dynamic spatial ability: An exploratory analysis and a confirmatory study. The International Journal of Aviation Psychology, 14(1), 19-38.

Dodwell, P. C. (1963). Children's understanding of spatial concepts. Canadian Journal of Psychology, 17(1), 141-161.

Eals, M., & Silverman, I. (1994). The hunter-gatherer theory of sex differences: Proximate factors mediating the female advantage in recall of object arrays. Ethology and Sociobiology, 15, 95-105.

El Koussy, A. A. H. (1935). The visual perception of space. British Journal of Psychology, 20, 1-80.

Fennema, E., & Sherman, J. A. (1977). Sex-related differences in mathematics achievement, spatial visualization and affective factors. American Educational Research Journal, 14(1), 51-71.

Flanery, R. C., & Balling, J. D. (1979). Developmental changes in hemispheric specialization for tactile spatial ability. Developmental Psychology, 15(4), 364-372.

Fruchter, B. (1954). Measurement of spatial abilities. Educational and Psychological Measurement, 14, 387-400.

Gages, T. T. (1994). The interrelationship among spatial ability, strategy used, and learning style for visualization problems. (Doctoral Dissertation, The Ohio State University, 1994). Dissertation Abstracts International, 55(11), 3399.

Galton, F. (1880). Statistics of mental imagery. Mind, 5, 300-318.

Galton, F. (1911). Inquiries into human faculty and its development. London: J.M. Dent & Sons.

Gardener, H. (1983). Frames of mind. *The Theory of Multiple Intelligence*.

Gardner, H. (1984). Frames of mind. New York: Basic Books.

Gardner, H. (1993). Multiple intelligences: The theory in practice. New York: Basic Books.

Gardner, R. W., Jackson, D. N., & Messick, S. J. (1960). Personality organization in cognitive controls and intellectual abilities (Monograph 8). Psychological Issues, 2(4).

Geiringer, E. R., & Hyde, J. S. (1976). Sex differences on Piaget's water-level task: Spatial ability incognito. Perceptual and Motor Skills, 42, 1323-1328.

Glasmer, F. D., & Turner, R. W. (1995). Youth sport participation and associated sex differences on a measure of spatial ability. Perceptual and Motor Skills, 81, 1099-1105.

Guilford, J. P. (1959). Three faces of intellect. American Psychologist, 14, 469- 479.

Guilford, J. P. (1967). The nature of human intelligence. New York: McGraw-Hill. Guilford, J. P. & Lacy, J. I. (1947). Printed classification tests. A.A.F. Aviation

Guilford, J. P., & Zimmerman, W. S. (1947a). Some A.A.F. findings concerning aptitude factors. Occupations, 26, 154-159.

Guilford, J. P., & Zimmerman, W. S. (1947b). The Guilford-Zimmerman aptitude survey – spatial orientation. Beverly Hills, CA: Sheridan Supply Company.

Gustafsson, J. (1988). Hierarchical models of individual differences in cognitive abilities. In R. J. Sternberg (Ed.), Advances in psychology of human intelligence (Vol. 4, pp. 35-71). Hillsdale, NJ: Lawrence Erlbaum Associates.

Guttman, L. (1954). A new approach to factor analysis: The radex. In P. F. Lazarsfeld (Ed.), Mathematical thinking in the social sciences (pp. 258- 348). Glencoe, IL: The Free Press.

Harris, L. J. (1978). Sex differences in spatial ability: Possible environmental, genetic, and neurological factors. In M. Kinsbourne (Ed.), Asymmetrical function of the brain (pp. 405-521). London: Cambridge University.

Harris, L. J. (1979). Sex-related differences in spatial ability: A developmental psychological view. In C. B. Kopp & M. Kilpatrick (Eds.), Becoming female: Perspectives on development (pp. 133-181). New York: Plenum Press.

Heitland, L. (2000a). Learning to make music enhances spatial reasoning. Journal of Aesthetic Education, 34(3-4), 179-237.

Heitland, L. (2000b). Listening to music enhances spatial-temporal reasoning: Eviden for the "Mozart Effect." Journal of Aesthetic Education, 34(3-4), 105-148.

Hill, D. M., & Obenauf, P. A. (1979). Spatial visualization, problem solving, and cognitive development in freshman teacher education students. Science Education, 63(5), 665-670.

Hiscock, M., Israelian, M., Inch, R., Jacek, C., & Hiscock-Kalil, C. (1995). Is there a sex difference in human laterality? II. An exhaustive survey of visual laterality studies from six neuropsychology journals. Journal of Clinical and Experimental Neuropsychology, 17(4), 590-610.

Humphreys, L. G., Lubinski, D., & Yao, G. (1993). Utility of predicting group membership and the role of spatial visualization in becoming an engineer, physical scientist, or artist. Journal of Applied Psychology, 78(2), 250-261.

Imperato-McGinley, J., Gautier, R., Voyer, D., & Bryden, M. P. (1991). Cognitive abilities in androgen insensitive subjects—Comparison with control males and females from the same kindred. Clinical Endocrinology, 34, 341-347.

Jagacinski, C. M., & Lebold, W. K. (1981). A comparison of men and women undergraduate and professional engineers. Engineering Education, 72, 213-220.

Johnson, E. S., & Meade, A. C. (1987). Developmental patterns of spatial ability: An early sex difference. Child Development, 58, 725-740.

Kelley, T. L. (1928). Crossroads in the mind of man. Stanford, CA: Stanford University Press.

Kimura, D. (1996). Sex, sexual orientation and sex hormones influence human cognitive function. Current Opinion in Neurobiology, 6(2), 259-263.

Kyllonen, P. C. (1981). Models of strategy and strategy-shifting in spatial visualization performance (Technical Report No. 17). Stanford University: California School of Education.

Kyllonen, P. C., Lohman, D. F., & Snow, R. E. (1984). Effects of aptitudes, strategy training, and task facets on spatial task performance. *Journal of Psychology,* 76(1), 130-145. doi: 10.1037/0022-0663.76.1.130

Kyllonen, P. C., Woltz, D. J., & Lohman, D. F (1981). Models of strategy and strategy-shifting in spatial visualization performance (Technical Report No. 17). Arlington, VA: Advanced Research Projects Agency.

Kyllonen, P. C., Lohman, D. F., & Woltz, D. (1984). Componential Modeling of Alternative Strategies for Performing Spatial Tasks. Journal of Educational Psychology, 76(6), 1325-1345.

Landau, M. S. (1984). The effects of spatial ability and problem presentation format on mathematical problem solving performance of middle school students. (Doctoral Dissertation, Northwestern University, 1984). Dissertation Abstracts International, 45(2), 442.

Lawton, C. A. (1994). Gender differences in way-finding strategies: Relationship to spatial ability and spatial anxiety. Sex Roles, 30, 765-779.

Linn, M. C., & Petersen, A. C. (1986). A meta-analysis of gender differences in spatial ability: Implications for mathematics and science achievement. In J. S. Hyde & M. C. Linn (Eds.), The psychology of gender: Advances through meta-analysis (pp. 67-101). Baltimore, MD: Johns Hopkins University Press.

Lohman, D. F. (1979a). Spatial ability: A review and re-analysis of the correlational literature (Technical Report No. 8). Stanford, CA: Aptitudes Research Project, School of Education, Stanford University.

Lohman, D. F. (1979b). Spatial ability: Individual differences in speed and level (Technical Report No. 9). Stanford, CA: Aptitudes Research Project, School of Education, Stanford University.

Lohman, D. F., & Kyllonen, P. C. (1983). Individual differences in solution strategy on spatial tasks. In R. F. Dillon & R. R. Schmeck (Eds.), Individual differences in cognition (Vol. 1, pp. 105-135). New York: Academic Press.

Lord, T. R., & Garrison, J. (1998). Comparing spatial abilities of collegiate athletes in different sports. Perceptual and Motor Skills, 86, 1016-1018.

Lowery, B. R., & Knirk, F. G. (1982-83) Micro-computer video games and spatial visualization acquisition. Journal of Educational Technology Systems, 11(2), 155-166.

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

Macnab, W., & Johnstone, A. H. (1990). Spatial skills which contribute to competence in the biological sciences. Journal of Biological Education, 24(1), 37-41.

Mann, V. A., Sasanuma, S., Sakuma, S., & Masaki, S. (1990). Sex differences in cognitive abilities: A cross-cultural perspective. Neuropsychologia, 28(10), 1063-1077.

Mason, S. F. (1986). Relationships among mathematical, musical, and spatial abilities. (Doctoral Dissertation, University of Georgia, 1986). Dissertation Abstracts International, 47(4), 1229.

McCuistion, P. (1989). Static vs. dynamic visuals in computer assisted instruction. (Doctoral Dissertation, Texas A&M University, 1989). Dissertation Abstracts International, 51(1), 144.

McCuistion, P. (1990). Static vs. dynamic visuals in computer assisted instruction. Proceedings of the American Society for Engineering Education Annual Conference and Exposition, 143-147.

McGee, M. G. (1976). Laterality, hand preference, and human spatial ability. Perceptual and Motor Skills, 42, 781-782.

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

McGee, M. G. (1979b). Human spatial abilities: Sources of sex differences. New York: Praeger Publishers.

McGlone, J. (1980). Sex differences in human brain asymmetry: A critical survey. The Behavioral and Brain Sciences, 3, 215-227.

McKee, L. D. (1983). Figure-drawing ability in solving mathematical problems. (Doctoral Dissertation, University of Georgia, 1983). Dissertation Abstracts International, 44(2), 417.

Metzler, J. (1973). Chronometric studies of cognitive analogues of the rotation of three-dimensional objects. (Doctoral Dissertation, Stanford University, 1973). Dissertation Abstracts International, 34(6), 2973.

Michaelides, M. P. (2002, April). Students' solution strategies in spatial rotation tasks. Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans, LA.

Michaelides, M. P. (2003, April). Age and gender differences in performance on a spatial rotation test. Paper presented at the Annual Meeting of the American Educational Research Association, Chicago, IL.

Moffat, S. D., & Hampson, E. (1996). A curvilinear relationship between testosterone and spatial cognition in humans: Possible influence of hand preference. Psycho-neuro-endocrinology, 21(3), 323-337.

Moody, M. S. (1998). Problem-solving strategies used on the Mental Rotations Test: Their relationship to test instructions, scores, handedness, and college major. Dissertation Abstracts International, 59(5), 2464.

Moses, B. E. (1977). The nature of spatial ability and its relationship to mathematical problem solving. (Doctoral Dissertation, Indiana University, 1977). Dissertation Abstracts International, 38(8), 4640.

Nash, S. C. (1975). The relationship among sex-role stereotyping, sex-role preference, and the sex difference in spatial visualization. Sex Roles, 1(1), 15-32.

Newcombe, N., Bandura, M. M., & Taylor, D. G. (1983). Sex differences in spatial ability and spatial activities. Sex Roles, 9(3), 377-386.

Nyborg, H. (1983). Spatial ability in men and women: Review and new theory. Advances in Behaviour Research and Therapy, 5(2), 89-140.

Olson, D. R. (1975). On the relations between spatial and linguistic processes. In J. Eliot & N. J. Salkind (Eds.), Children's spatial development (pp. 67-110). Springfield, IL: Charles C. Thomas.

Orde, B. J. (1996). A correlational analysis of drawing ability and spatial ability. Dissertation Abstracts International, 57(5), 1943.

Pak, R. (2001, October). A further examination of the influence of spatial abilities on computer task performance in younger and older adults (pp. 1551- 1555). Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting, Minneapolis, MN.

Pearson, J. L., & Ferguson, L. R. (1989). Gender differences in patterns of spatial ability, environmental cognition, and math and English achievement in late adolescence. Adolescence, 24(94), 421-431.

Pellegrino, J. W., & Hunt, E. B. (1989). Computer-controlled assessment of static and dynamic spatial reasoning. In R. F. Dillon & J. W. Pellegrino (Eds.), Testing: Theoretical and applied perspectives (pp. 174-198). New York: Praeger.

Pellegrino, J. W., & Hunt, E. B. (1991). Cognitive models for understanding and assessing spatial abilities. In H. A. H. Rowe (Ed.), Intelligence: Reconceptualization and measurement (pp. 203-225). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Pellegrino, J., Alderton, D., & Shute, V. (1984). Understanding spatial ability. Educational Psychologist, 19(3), 239-253.

Piaget, J., & Inhelder, B. (1967). Child's conception of space (F. W. Langdon & J. L Lunzer, Trans.). New York: Norton.

Piaget, J., & Inhelder, B. (1971). *Mental Imagery in the child.* New York: Basic Books, Inc.

Poltrock, S. E., & Agnoli, F. (1986). Are spatial visualization ability and visual imagery ability equivalent? In R. J. Sternberg (Ed.), Advances in the psychology of human intelligence (Vol. 3, pp. 255-296). New Jersey: Lawrence Erlbaum Associates.

Poltrock, S. E., & Brown, P. (1984). Individual differences in visual imagery and spatial ability. Intelligence, 8, 93-138.

Rilea, S. L., Roskos-Ewoldsen, B., & Boles, D. (2004). Sex differences in spatial ability: A lateralization of function approach. Brain and Cognition, 56, 332- 343.

Robichaux, R. R. (2000). The spatial visualization of undergraduates majoring in particular fields of study and the relationship of this ability to individual background characteristics. (Doctoral Dissertation, Auburn University, 2000). Dissertation Abstracts International, 61(1), 119.

Robichaux, R. R., & Guarino, A. J. (2000, November). Predictors of visualization: A structural equation model. Paper presented at the Annual Meeting of the Mid-South Educational Research Association, Bowling Green, KY.

Saccuzzo, D. P., Craig, S., Johnson, N. E., & Larson, G. E. (1996). Gender differences in dynamic spatial abilities. Personality and Individual Differences, 21(4), 599-607.

Salthouse, T. A., & Mitchell, D. R. D. (1990). Effects of age and naturally occurring experience on spatial visualization performance. Developmental Psychology, 26(5), 845-854.

Salthouse, T. A., Babcock, R. L., Mitchell, D. R. D., Palmon, R., & Skovronek, E. (1990). Sources of individual differences in spatial visualization ability. *Intelligence,* 14,187-230. doi:10.1016/0160-2896(90)90004-D

Shepard, R. N. (1978). The circumplex and related topological manifolds in the study of perception. In S. Shye (Ed.), Theory construction and data analysis in behaviorial sciences (pp. 29-80). San Francisco: Jossey-Bass.

Sherman, J. A. (1967). Problem of sex differences in space perception and aspects of intellectual functioning. Psychological Review, 74(4), 290-299.

Sherman, J. A. (1974). Field articulation, sex, spatial visualization, dependency, practice, laterality of the brain and birth order. Perceptual and Motor Skills, 38, 1223-1235.

Silverman, I., & Eals, M. (1992). Sex differences in spatial abilities: Evolutionary theory and data. In J. Barkow, L. Cosmides, & J. Tooby (Eds.), The adapted mind: Evolutionary psychology and the generation of culture (pp. 487-503). New York: Oxford University Press.

Silverman, I., Choi, J., & Peters, M. (2007). The hunter-gatherer theory of sex differences in spatial abilities: Data from 40 countries. *Archives of Sexual Behavior,* 36(2), 261-268. doi: 10.1007/s10508-006-9168-6

Smith, I. M. (1964). Spatial ability, its educational and social significance. San Diego, CA: Robert R. Knapp.

Smith, W. S., & Litman, C. I. (1979). Early adolescent girls' and boys' learning of a spatial visualization skill. Science Education, 63(5), 671-676.

Smith, W. S., & Schroeder, C. K. (1979). Instruction of fourth grade girls and boys on spatial visualization. Science Education, 63(1), 61-66.

Stumpf, H., & Klieme, E. (1989). Sex-related differences in spatial ability: More evidence for convergence. Perceptual and Motor Skills, 69, 915-921.

Thorndike, E. L. (1921). On the organization of the intellect. Psychological Review, 28, 141-151.

Thurstone, L. L. (1938). Primary mental abilities. *Psychometric Monographs,* No. 1.

Thurstone, L. L. (1944). A factorial study of perception. Chicago: University of Chicago Press.

Thurstone, L. L. (1950). Some primary abilities in visual thinking. Chicago, IL: University of Chicago Psychometric Lab Report No. 59.

Tracy, D. M. (1990). Toy-playing behavior, sex-role orientation, spatial ability, and science achievement. Journal of Research in Science Teaching, 27(7), 637-649.

Vandenberg, S. G. (1971). *The Mental Rotations Test.* Boulder: University of Colorado.

Vandenberg, S. G. (1975). Sources of variance in performance on spatial tests. In J. Eliot & N. J. Salkind (Eds.), Children's spatial development (pp. 57- 66). Springfield, MA: Thomas.

Vandenberg, S. G., & Kruse, A. R. (1978). Mental Rotations, a Group Test of Three-Dimensional Spatial Visualization. Perceptual and Motor Skills, 47, 599-604.

Vandenberg, S. G., & Kuse, A. R. (1978). Mental rotations, a group test of three-dimensional spatial visualization. *Perceptual and Motor Skills, 47,* 599-604.

Vandenberg, S. G., & Kuse, A. R. (1979). Spatial ability: A critical review of the sex-linked major gene hypothesis. In M. A. Wittig & A. C. Petersen (Eds.), Sex-related differences in cognitive functioning (pp. 67-95). New York: Academic Press.

Vandenberg, S. G., Stafford, R. E., & Brown, A. M. (1968). The Louisville twin study. In S. G. Vandenberg (Ed.), Progress in human behavior genetics: Recent reports on genetic syndromes, twin studies, and statistical advances (pp. 153-204). Baltimore: John Hopkins Press.

Vederhus, L., & Krekling, S. (1996). Sex differences in visual spatial ability in 9- year-old children. Intelligence, 23, 33-43.

Walker, J. T., Krasnoff, A. G., & Peaco, D. (1981). Visual spatial perception in adolescents and their parents: The X-linked recessive hypothesis. Behavior Genetics, 11(4), 403-413.

Wheatley, G. H., Brown, D. L., & Solano, A. (1994). Long term relationship between spatial ability and mathematical knowledge. Paper presented at the 16th Annual Meeting of the Psychology of Mathematics Education.

Witkin, H. A. (1949). The nature and importance of individual differences in perception. Journal of Personality, 18, 145-170.