CHAPTER II

REVIEW OF RLATED LITERATURE

2.0 Introduction

In this first chapter, Rationale along with Objectives and Hypotheses has been given. The present chapter is devoted to reviewing researches related to different aspects of Spatial Ability and its relationship with other abilities. For better understanding the researches have been classified under the captions as follows. This chapter presents an overview of the different spatial factors being coded among visually impaired and sighted persons.

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2.1 A Historical Review of Spatial Abilities

The history of research concerning spatial ability can be broken into three general phases of research activity. Eliot and Smith (1983) described these phases in terms of efforts in defining spatial ability: In the first phase (1904-1938), researchers investigated the evidence for and against the existence of a spatial factor over and above a general factor of intelligence. In the second phase (1938-1961), they attempted to ascertain the extent to which spatial factors differed from one another. And in the recent phase (1961-1982), researchers have attempted to designate the status of spatial abilities within the complex interrelationship of other abilities and to examine a number of sources of variance which affect performance on spatial tests (Elliot & Smith 1983).

Charles Spearman (1904) published an influential report regarding a two-factor theory of intelligence. Spearman noticed that children's' grades across seemingly distinct subjects were positively correlated and proposed that these correlations suggested the influence of a central factor, which he referred to as "g" for general intelligence. They claimed that the theory was able to account for all variations in intelligence through the use of multiple factors. The first factor, "g" represented a universal ability that directed performance on all cognitive tasks. In addition, "s" factor represented specific abilities that were assumed to be associated with each individual test.

After the publication of Spearman's two-factor theory of intelligence, many researchers worked to identify group factors which would be inconsistent with Spearman's "s" factors. One factor of interest was spatial ability. Researchers focused on providing evidence for and against the existence of a common spatial factor in addition to the general factor of intelligence (Elliot & Smith 1983).

Stoy, E.G (1927) Conducted tests which would differentiate between individuals with and without an aptitude for mechanical drawing. The participants consisted of high school freshmen who were taking their second semester of mechanical drawing. Participants were selected by their teachers based on promise or lack of promise in mechanical drawing. A total of 31 promising and 28 unpromising students participated in the experiment. Stoy administered a total of 13 separate aptitude tests concerned with spatial relations, motility, and mechanical ingenuity. Of the13 tests, six showed significant group differences between the promising and unpromising students. The six tests, which Stoy believes to be useful in mechanical drawing aptitude testing, included Thurstone-Jones Problem 4 (Paper Folding), Minnesota Paper Form Board, Downey Group Test V (Coordination of Impulses), Downey Group Test III (Flexibility), Painted Cube test, and Freeman Puzzle Box (Stoy, 1927). From the results of this experiment, it was Stoy's hope to develop enough useful tests to make a comprehensive study of aptitude for drafting.

Dewey Anderson (1928) described three mechanical ability tests that were developed at the University of Minnesota by a research organization subsidized by the Committee on Human Migration of the National Research Council. Each test was created in reaction to the unsuitable tests used in company placement programs despite the fact that the tests displayed low reliability and unproven validity.

The first test Anderson described was The Minnesota Assembly Test, which is a modified version of the original Stenquit Assembly Test. The Stenquit Assembly Test was developed in 1914 as a test for mechanical ability; however, since it did not exhibit reliability or consistency, it was revised into The Minnesota Assembly Test. The newer version of the test consisted of a number of mechanical devices that were disassembled, the participants were then instructed to assemble the parts of each device, and the accuracy with which this was done provided an index of mechanical ability. The original Stenquit test contained only ten items; however, to make the Minnesota Assembly Test more reliable an additional 24 items were added to the original ten. Another modification made to the test was the method of administration. The original test set a time limit for completion of the whole test; however, the new version set time limits for each item within a series.

The second test Anderson described was The Paper Form Board Test. The basis of this test was developed by the Army Group Examination Beta, Form O and consisted of items where there is a large figure and two or more smaller ones, which are segments of the larger one. The participant indicated by drawing lines in the large figure how the smaller ones could be fitted into it (Anderson, 1928).

Finally, the last test Anderson described was The Spatial Relations Test. This test was based on the form board test created by Dr. H.C. Link. It included two cut-out boards and one set of blocks. The blocks were placed on one board by the experimenter and then turned over on a table so that the blocks would fall out. The participant then tried to place the blocks in the same order as the experimenter had on a second board. This test was not long enough to provide a high sense of reliability, so in the newer version two pairs of boards were made, each containing 54 cut outs (Anderson, 1928). Another modification made to the test was to use boards that contained no back base so that when the board was lifted the blocks fell onto the table without being inverted.

Anderson's purpose in describing these three tests, which were high in reliability and validity, was to inform industrial psychologists of the advantages in using these reliable means of measuring mechanical ability.

Although the exact number of subdivisions of the spatial factor is not universally agreed upon, the most current research no longer tries to differentiate between subdivisions. In general, most researchers will agree to the notion of at least three broad and widely researched subdivisions (Visualization, Spatial Relations, and Spatial Orientation) and seven smaller, less frequently researched subdivisions (Flexibility of Closure, Closure Speed, Spatial Scanning, Perceptual Speed, Serial Integration, Visual Memory, and Kinesthetic) (Lohman, 1984). More recently, research has focused on the inter-correlations between spatial abilities and other abilities and on the different sources of variation in performance on spatial tests.

Factors like Closure Speed, Perceptual Speed, Visual Memory, and Kinesthetic may represent individual differences in the speed or efficiency of these basic cognitive processes. However, these factors surface only when extremely similar tests are included in a test batter. Such tests and their factors consistently fall near the periphery of scaling representations, or at the bottom of a hierarchical model (Lohman 1979).

Lohman later listed a total of ten spatial factors which included the addition of three other minor spatial factors: Flexibility of Closure, Spatial Scanning, and Serial Integration (Lohman, Pellegrino, Alderton, & Regian, 1987).

Lansman et al. (1982) conducted a study concerned with relations between abilities measured by paper-and-pencil methods and those measured by an experimental laboratory setting. They attempted to relate ability factors (fluid intelligence, crystallized intelligence, spatial visualization, and clerical perceptual speed) to measures of subjects' speed of information processing.

2.2 Concept of Spatial Ability: Different Views

Michael et al (1951) conducted a study which administered a total of seven spatial ability tests and eight reference tests to 151 male and 139 female participants ranging in age from 15 to 20. Separate analyses were performed for each group, and both groups produced six identifiable factors: Visualization, Spatial Relation, Number, Verbal, Perceptual Speed, and Reasoning. Michael et al. concluded that "the factor pattern in each test was approximately the same for the two groups". Michael et al. also concluded that sex differences in spatial ability were found. The results indicated that males outperformed females on most of the spatial abilities.

Zimmerman (1954) carried out a study that sought to determine the comparative factor structure of three forms of the AAF experiment through the use of factor analysis. Zimmerman's study established that by increasing the difficulty of items on an AAF test, a test could be formed to stress a perceptual speed factor, a space factor, and a visualization factor. In experiment, Zimmerman used the *Visualization of Maneuvers* test and increased the difficulty of the test throughout the experiment. The easiest experiment required participants to choose which picture correctly represented an airplane's position after it had performed a specific maneuver. The test of medium difficulty required the participant to complete the same procedure after imagining the plane completing two given maneuvers, and the most difficult test required the participant to choose after the plane had completed three maneuvers. Zimmerman claimed that, "The easier form had the highest loading on perceptual speed. The test of medium difficulty led the others on space, and the most difficult of the three led the others with a heavy weight in Visualization". Thus, Zimmerman was able to provide some evidence for the notion of a hierarchy of spatial factors.

Spivey (2009) showed that the spatial concepts (a category of basic concepts) define the relationship between us and objects, as well as the relationships of objects to each other. As our language begins to develop, early spatial concepts such as in front of, behind, top, bottom, over, under, last, between, farthest, backward, in, on, etc., help us understand directions more precisely, ask detailed questions, and express our ideas to others. For preschoolers and young students, an awareness or understanding of spatial concepts and relationships usually predicts later success in math, reading, and following directions.

Lohman (1993) explored that the spatial abilities have long been relegated to a secondary status in accounts of human intelligence. Tests of spatial abilities are viewed as measures of practical and mechanical abilities that are useful in predicting success in technical occupations, but not as measures of abstract reasoning abilities (Smith, 1964). This conflicts with the important role afforded to spatial imagery in accounts of creative thinking (Shepard, 1978), and with the observed correlations between spatial tests and other measures of intelligence. In fact, Spearman (see Spearman & Wynn Jones, 1950) considered spatial tests merely as unreliable measures of G. Hierarchical factor analyses generally support Spearman's conclusion, especially for complex spatial tests. Such tests are primarily measures of G, secondarily measures of something task-specific, and thirdly, measures of something that covaries uniquely with performance on other spatial tasks (Lohman, 1988). Simpler, speeded spatial tasks show lower G loadings, higher task specific loadings, and higher spatial factor loadings. In this paper, I first summarize and then attempt to explain these findings. The relationship between spatial task performance and G may reflect both statistical artifacts and psychological factors. Psychological factors include the attentional demands of maintaining and transforming images in working memory (Kyllonen & Christal, 1990) and the importance of mental models in reasoning (Johnson-Laird, 1983). Indeed, one can turn Spearman's conclusion around and with equal conviction conclude that measures of G are by and large unreliable measures of the ability to generate and coordinate different types of mental models in working memory. Evidence that supports and challenges such a conclusion is reviewed.

Kitchin, Mark Blades & Golledge (1997) reviewed the literature that has sought to determine the spatial understanding of people with visual impairments or blindness. In particular, they examine the arguments surrounding whether people with visual impairments or blindness can understand geographic relationships such as distance, configuration and hierarchy. At present, the conclusions of researchers can be divided into three camps. One group suggests that vision is the spatial sense par excellence. This group suggests that congenitally blind individuals (blind from birth) are incapable of spatial thought because they have never experienced the perceptual processes necessary to comprehend spatial arrangements. Another group suggests that people with visual impairments can understand and mentally manipulate spatial concepts, but because information is based upon auditory and haptic cues this knowledge and comprehension is inferior to that based upon vision. The third group suggests that visually impaired individuals possess the same abilities to process and understand spatial concepts and that any differences, either in quantitative or qualitative terms, can be explained by intervening variables such as access to information, experience or stress. To date, most of the research which has led to these conclusions has been conducted using small-scale, laboratory environments and, as yet, they are still unsure as to how people with visual impairments and blindness learn store and process spatial information at the geographic scale. They suggest that more research is needed to understand more fully the `mental landscapes' of people with blindness or visual impairments. Such research is necessary, particularly given the rapid growth of orientation and navigation aids in recent years aimed at increasing independent mobility. The research must move out of the laboratory to examine spatial thought within the geographic environments that people with visual impairments or blindness interact with on a daily basis.

Golledge (1992) examined whether people in general understand elementary spatial concepts, and to examine whether or not naive spatial Knowledge include the spatial ability to understand important spatial primitives that are built into geographic theory, spatial databases and geographic information system (GIS). The extent of such understanding is a partial measure of spatial ability. Accurate indicators or measures of spatial ability can be used to explain different types of spatial behavior. In this paper I fast examine the relation between spatial ability and spatial behavior, then present Experimental evidence of the ability of people to understand spatial concepts such as nearest neighbors (proximity), and spatial distributions. A final commentary made about the possible difference between" common sense" and "expert" spatial knowledge and the implications of such results for the comprehension of space at all scales.

2.3 Importance of Spatial Abilities

Self, Gopal, Golledge & Fenstermaker (1992) showed that the Spatial abilities include: the ability to think geometrically; the ability to image Complex spatial relations at various scales, from national urban systems to interior room designs or tabletop layouts; the ability to recognize spatial patterns in distributions of functions, places and interactions at a variety of different scales; the ability to interpret macro spatial relations such as star patterns; the ability to give and comprehend directional and distance estimates as required by navigation, or the path integration and short-cutting procedures used in way finding; the ability to understand network structures used in planning, design and engineering; and the ability to identify key characteristics of location and association of phenomena in space. This definition next ends beyond that usually found in discussion of spatial aptitude tests, but includes traditional things such as orientation and re-orientation after rotation, translation (or other transformation), perspective viewing, knowing locations, and integrating partial (line arized) information into configurationally wholes.

Cooper & Mumaw (1985) showed that a broadly defined spatial factor exists independently of verbal and quantitative factors”. The spatial ability is an important component of the intellectual ability, there is no consensus on the nature of the phenomenon. 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". Therefore, different kinds of spatial abilities have been proposed based on factor analytic studies.

Sinan Olku, Hoffer & Hoffer (1992) eliminated Porter (1989) stated that Spatial thinking is essential for scientific thought; it is used to represent and manipulate information in learning and problem solving (Clements & Battista, 1992). It is also required in many intellectual endeavors such as solving problems in engineering, design, physics and mathematics (Smith, 1964; Pellegrino, Alderto n & Shute, 1984). Enhancing students' spatial abilities is one of the roles of geometric activities. The National Council of Teachers of Mathematics recommends "the mathematics curriculum for grade 5- 8 should include the study of the geometry of one, two, and three dimensions in a variety of situations, so that students can visualize and represent geometric figures with special attention to developing spatial sense" (NCTM, 1989). However, such is not the case. Current geometry curricula do not provide enough opportunities for the development of spatial ability (Usiskin, 1987). Moreover, in many schools geometry is delayed until the end of the school year.

Yamamoto T (1990) investigated the development of spatial problem solving ability in early blind. Thirty-one pupils at elementary schools (ages between six years and nine month and 12 years and two months) and seven adults were tasted using the method developed by Yamamoto and Tatsuno (1984) to investigate the development of spatial ability in the early blind. The subjects walked, with the guidance of the experimenter, on a path which had 45, 90, or 135 degree right or left angle turn at its middle point. At the end point of each path, the subjects walked back alone to find the starting point of the path. The trials were repeated 12 times. The adult group made less angular error in the direction of movement when they walked back alone, though other performance measures scarcely showed any indications of development of the ability. The subjects' verbal reports concerning their problem solving methods revealed that many of them were using the starting point as an anchor while they were walking. The data obtained were evaluated with reference to the earlier data for the sighted [Yamamoto & Tatsuno's (1984) data]. Some points of agreement and disagreement with the argument of put forward by Juurmaa (1973) and the present results concerning the development of spatial ability were also discussed.

Yamamoto (1990) conducted an Experiment concerning spatial orientation in a large space. In the following experiment, children in a classroom in a primary school were asked to point out the directions where the main gate, swimming pool entrance, gymnasium entrance and the like are located .Subjects could walk alone to those places. As the number of primary school children of early blind children to be subjects was small, one group consisted of blind children in 1st through 3rd grades of and another consisted of those in 4th through 6th grades. And a group of sighted children consisted of those in 2nd through 5th grade primary school students. The result indicated that the spatial orientation of early blind children was imprecise. Different from the results obtained from the experiment conducted in a small space, sighted children indicated spatial orientation more precisely, and the difference between sighted children and visually impaired and blind children became much larger in older children.

Yamamoto T (1991) conducted a study on development of the spatial problem solving ability in the early blinds, 27 children of schools for the blind (8: 11 to 14: 11 years old), who participated in the Yamamoto's (1990) experiment two years ago, were re-tested using the same method as before. Five blind children (6: 3 to 7: 10 years) were also newly added. Subjects walked, with the guidance of the experimenter, on a route from the first to the third points. After reaching the third point of each route, subjects were required to walk back by him/herself to the first point. The trials were repeated 12 times using different routes. Subjects revealed less angle errors and less distance errors than in the previous experiment, but they did not show any change in the percentage of "longer turns" at the third Pont. The subjects' trails of walking changed from the nonlinear to the linear types as a function of age. Differences in the three performance measures and the developmental changes in the walking-trails of children were discussed, the latter with reference to the developmental transition of the spatial ability from the route to the survey types.

Teli Karaman & Ayşenur Yontar Toğro (1993) reported that the plane geometry subject includes concepts as points, lines, planes, space and their relations.

Representations of three-dimensional objects by means of two-dimensional diagrams bring the difficulties of identification of their properties. Three sub-factors of spatial ability were identified as the main variables in the performances of students related to plane geometry subject. The purpose of this study is to investigate the relationship between gender, spatial visualization, spatial orientation, flexibility or speed of closure abilities and the performances related to the plane geometry subject of the sixth grade students. The sample of the study consisted of 120 sixth grade students. In the first part of the study, the reliability and the validity studies of the representative tests were carried out. In the second part, correlation analyses were carried out. Significant correlations were found between each factor except gender. For clarifying the relationships between more than one factor multiple regression analyses were used. The results showed that the three predictor variables explained the 35 per cent of the variance in plane geometry test scores. The, degree of contribution of each factor differed. The relative impact of spatial orientation ability (B=. 41) was higher than the spatial visualization ability (B=. 26) followed by the flexibility of closure ability (B=. 05). As a result of correlation analysis, gender was not taken into the regression analyses. The plane geometry subjects in the National curriculum were analyzed and related suggestions were carried out in line with the research findings.

2.4 Influence of Spatial Thinking

Christos Charcharos, Margarita Kokla, & Eleni Tomai (2016) reported that Spatial thinking has been acknowledged as an important interdisciplinary ability relevant to many aspects of everyday life, workplace, and science. Recently, researchers begun to explore the relation between spatial thinking and other high level skills and its capacity to constitute a new approach to learning (learn to learn), differing from the more established auditory sequential type of learning. The present paper explores whether spatial thinking is associated with another high level cognitive skill: problem solving. The aim is to design an experiment that will determine the relation (if any) between these skills. Eligible participants for this experiment are both males and females under 25 years old. The participants' spatial thinking (including both small and large scale factors) and problem solving skills (including analytic and interactive) will be estimated through various questionnaires, such as from the Spatial Thinking Ability Test (STAT), the Programme for International Student Assessment

(PISA), and the Programme for the International Assessment of Adult Competencies (PIAAC Project). Regarding the statistical analysis of the results firstly, the normality of the collected data will be calculated and depending on the results, the appropriate methods will be used to estimate the kind of correlation (positive or negative) between spatial thinking and problem solving skills. Moreover, a stepwise multiple regression analysis will be conducted to determine the relative contribution of age and spatial thinking to problem solving.

Charcharos, Kokla & Tomai (2015) in their study found out that the Spatial (and geospatial) thinking has been well studied and recognized as an important ability of humans and especially for young people and young adults, who most of the times use it subconsciously, from interpreting maps and diagrams to navigating in familiar and non-familiar environments. However, spatial thinking ability is not easy to estimate, because spatial thinking is an amalgam of different factors (e.g. spatial perception, spatial orientation, spatial visualization, mental rotation etc.). Various tests have been developed, especially from teachers and psychologists, which in their majority assess one factor of spatial thinking, either at small scales or large scales, but no test has been developed yet from researchers engaged in the Geographic Information field to assess spatial thinking in a holistic way. So, this paper underlines the need to develop such a test.

2.5 Components of Spatial Ability

2.5.1 Distance Estimation

Marlone, Henderson, Chtheery, Wakslak, Kentaro Fujita & John Rohrbach (2011) found the growing evidence points to a bidirectional relationship between spatial distance and level of mental representation, whereby distant (vs. near) events are represented by a higher level of representation, and higher levels of representations increase perceptions of distance. In the current article, they review research that establishes this association and explores its implications. They begin by briefly describing construal level theory, the theoretical framework that gives rise to this associative prediction, and then review a set of theory- consistent findings that serve to illuminate the way that spatial distance influences cognition and behavior and the way in which people make judgments about spatial distance. Finally, they discuss open questions for future research on spatial distance using a construal level theory approach.

Klatzky, Susan & Lederman (2003) found that Representing Spatial Location and Layout from Sparse Kinesthetic Contacts Participants' fingers were guided to 2 locations on a table for 3 s, then back to the start. They reported distances and angles between the locations by (a) replacing 1 or 2 fingers, (b) translating the contacted configuration, or (c) estimating distance or angle alone. Distance error increased across these conditions. Angular error increased when the angular reference axis was rotated before the response. Replacing 1 finger was impaired by a change in posture from exposure to test. The results suggest a kinesthetic representation is used to replace the fingers, but to estimate distance and angle at new locations, a configural representation is computed. This representation is oriented within an extrinsic reference frame and maintains shape more accurately than scale.

Susan, Lederman & Klatzky (1987) revealed that in Experimental I, blind-folded observers judged (a) the distance of pathways felt by hand and (b) the straight -line distance between pathway endpoints inferred from such exploration. In Experiment 2, blind-folded observers made corresponding estimates after traversing similar pathways on foot. Pathways were explored under three different speeds. Under both manipulatory and ambulatory exploration, there was substantial length distortion of inferred distance. The straight-line distance was increasingly overestimated with increases in the length of the explored pathway. With manipulatory exploration, slower movements increased length distortion, but duration effects proved secondary to effects of spatial extent. For ambulatory exploration, no duration effects were obtained. Observer used time-independent heuristics, that is, a footstep metric for estimating the pathway actually travelled and a spatial imaging strategy for estimating the inferred line between pathway endpoints. The studies establish length distortion as a general phenomenon in movement space and identify its major causes as spatial rather than temporal.

Middle brooks & Green (1991) showed that Estimation of the direction and distance of a sound is possible for a but this appears imprecise and limited. Obviously, sound intensity varies as an inverse function of the distance from the source, this estimate implies that the participant has information about the sound intensity at its source to scale for distance, that is, he or she has some reference level with which to compare. Although some particular strategies are set up by blind persons to mitigate these limitations and optimalize sound information (Mershon& Bowers, 1979), they must conclude that audition as a source of spatial information has severe accuracy limitations.

Barber & Lederman (1988) found out that the congenitally blind, adventitiously blind, and blind-folded sighted adults made direction estimates of target position within manipulator space after their index fingers were guided to each target from a neutral starting point. Observers remained seated in the same location throughout the experiment. In a “finger-movement” condition, observers’ fingers were guided to a target location from which they pointed to each of the other targets. In an “imagination” condition, the observers pretended they were at one of the target locations and pointed to the other targets as is they occupied the new target position. Regardless of visual experience, observers in the finger-movement task were more accurate but only negligibly faster than in the imagination task. The subjective reports of all groups suggested that cognitive-mapping heuristics were used in both tasks, contrasting with previous results obtained in ambulatory space (Rieser,Guth, & Hill, 1982). The results are considered in the light of a fundamental difference between manipulatory and ambulatory space.

Finocchietti, Cappagli, & Gori (2015) conducted a study concerning of blindness on auditory spatial localization has been an interesting issue of research in the last decade providing mixed results. Enhanced auditory spatial skills in individuals with visual impairment have been reported by multiple studies, while some aspects of spatial hearing seem to be impaired in the absence of vision. In this study, the ability to encode the trajectory of a 2-dimensional sound motion, reproducing the complete movement, and reaching the correct end-point sound position, is evaluated in 12 early blind (EB) individuals, 8 late blind (LB) individuals, and 20 age-matched sighted blind-folded controls. EB individuals correctly determine the direction of the sound motion on the horizontal axis, but show a clear deficit in encoding the sound motion in the lower side of the plane. On the contrary, LB individuals and blind-folded controls perform much better with no deficit in the lower side of the plane. In fact the mean localization error resulted 271 ± 10 mm for EB individuals, 65 ± 4 mm for LB individuals, and 68 ± 2 mm for sighted blind-folded controls. These results support the hypothesis that (i) it exists a trade-off between the development of enhanced perceptual abilities and role of vision in the sound localization abilities of EB individuals, and (ii) the visual information is fundamental in calibrating some aspects of the representation of auditory space in the brain.

Ungar, Blades, & Spencer (1997) in their study involved Visually Impaired Children to Make Distance Judgments from a Tactile Map. In Experiment 1, totally blind children, children with residual vision, and sighted children were given a map showing the position of three objects on a path, two of which were present on the actual path. The children were asked to use the map to work out the position of the third object. The visually impaired children performed less well than did the sighted children, and an analysis of the children's strategies indicated that the majority of visually impaired children did not know an effective way to work out distances from the map. In Experiment 2, the visually impaired children were given a brief training in how to calculate distances from a map and then they were retested. After training, the children's performance improved.

Wanet & Veraart (1985) showed that early blind participants' distance evaluation of a sound source is impaired. The deficit in distance evaluation was greater when the participants had to point with their hand toward the target than when they were required to name the coordinates of the estimated position of the sound source. In contrast, errors of direction estimation were greater when the participant gave verbal indications. In a simpler experiment, the task consisted of only the participant estimating the loHaber,

Fisher (1964) compared auditory and tactile localization and found that congenitally and late blind participants displayed poorer performance than blind-folded sighted participant when the response consisted of turning their head toward the target but not when they were asked to verbally indicate which stimulus was farther to the left. However, in this last condition, the required evaluation was less precise than when they had to orient their head toward the target because it required only a comparison between two target sounds.

2.5.2 Mental Rotation

Harris, Hirsh-Pasek & Newcombe (2013) found out the mental rotation and mental folding, two widely used measures of spatial ability, both require the dynamic spatial transformation of objects with respect to their internal spatial structure. Traditionally, however, these two skills have been considered quite distinct, based primarily on factor analyses of psychometric data. This paper reviews the similarities and differences between mental rotation and mental folding from a variety of perspectives, including their definitions, component cognitive processes, neurological bases, developmental trajectories, malleability, predictive validity, and psychometric properties. They conclude that mental rotation and mental folding are similar in many respects. However, the tasks differ in whether they require rigid or non-rigid transformations of objects. In addition, mental rotation shows robust sex-related differences whereas mental folding does not. They also identify specific questions for which research is lacking.

Peter Khooshabeh & Mary Hegarty (2010) investigated the format of mental representations of 3-D shapes during mental rotation. Specifically, they tested the extent to which visual information, such as color, is represented during mental rotation using methods ranging from reaction time studies, verbal protocol analysis, and eye tracking. Another set of studies examined whether people use piecemeal or holistic strategies to rotate complex objects. Results show that individuals with good rotation ability do not represent color during mental rotation and rotate whole shapes; whereas poor rotators do represent color and rotate individual pieces of the shape using piecemeal strategies. This work contributes to theories about cognitive shape processing by showing that different information processing strategies may be one cause of individual differences in mentally rotation performance.

Marcel Adam Just, Patricia, Carpenter, Mandy Maguire, Vaibhav Diwadkar, & Stephanie McMains (2001) examined how people mentally rotate a 3-dimensional object (an alarm clock) that is retrieved from memory and rotated according to a sequence of auditory instructions. They manipulated the geometric properties of the rotation, such as having successive rotation steps around a single axis versus alternating between two axes. The latter condition produced much more activation in several areas. Also, the activation in several areas increased with the number of rotation steps. During successive rotations around a single axis, the activation was similar for rotations in the picture plane and rotations in depth. The parietal (but not extra-striate) activation was similar to mental rotation of a visually presented object. The findings indicates that a large-scale cortical network computes different types of spatial information by dynamically drawing on each of its components to a differential, situation-specific degree.

Shepard, & Metzler (1971) Described the Mental rotation of three-dimensional objects. Science has been applied in a broad range of studies on mental rotation. This note provides a brief background on these figures, their general use in cognitive psychology and their role in studying spatial behavior. In particular, it is pointed out that large sex differences with the 3D mental rotation figures tend to be observed only in particular tasks, such as the Vandenberg and Kuse test Vandenberg, S.G., & Kuse, A.R. (1978). Mental rotations, a group test of three-dimensional spatial visualization. Perceptual and Motor Skills that involves multiple figures within a single problem. In contrast, pair wise presentation of the same 3D figures yields either small or no significant sex differences. In the context of the very broad range of ongoing research done with 3D figures, and the desirability of uniformity in the stimulus material used, they introduce a library of 16 cube mental rotation figures, each presented in orientations ranging from 0 to 360 degree in 5 degree steps, and with its mirror image, for a total of 2336 figures. This library, freely available to researchers, will help in the creation of mental rotation tasks both for presentation on the computer screen and for pencil and paper applications.

Pazzaglia & De BeniR (2006) found that the alignment effect is influenced by mental rotation abilities. In two experiments, groups of undergraduate students with high and low performance in mental rotation tasks were required to study either schematic (experiment 1) or more complex (experiment 2) maps, and to perform a number of pointing tasks adopting a perspective which could be aligned, misaligned (45 degrees, 135 degrees), or counter aligned (180 degrees) with the perspective assumed during learning. Cognitive styles in spatial representation have also been considered. Results of experiment 1 show that people with low performance in mental rotation tasks prefer to adopt a representation of space focused more on landmarks. Their performance in the pointing tasks depends on the alignment conditions, with more errors in the counter aligned condition followed by the two misaligned and aligned ones. In contrast to this, high-ability mental rotators prefer survey and route spatial representations and are affected only by the aligned and non-aligned conditions. In the second experiment, practice was studied as a function of mental rotation and alignment. The group high in mental rotation ability was found to be free from the alignment effect in the pointing tasks performed after the final of four learning phases.

Kosslyn, Ball, & Reiser (1978) involved participants to scan a mental map after studying a map of an island with several landmarks. They predicted that the further the distance between the landmarks, the longer it would take participants to scan from one to the next, whether using the actual map or a mental image created by intensive study. Their hypothesis was supported by their results. The closer positions took less time to locate on the participant' mental maps than the more distant places.

Cooper & Shepard (1973) studied participants to perform a mental rotation task. They gave the participants an image, and asked them to rotate it mentally by a certain angle, and then match the rotated image with one of several choices. Their prediction was that the greater the angle of rotation, the longer the task would take. This was because it would take longer to physically rotate a figure more degrees than fewer degrees. The evidence supported this hypothesis: The closer the angle is to 180 degrees, the longer the reaction time. Angles greater than 180 degrees do not take longer because the subject will rotate it in the other direction. So the angle distance from 180 degrees, called the angle of disparity, is directly related to the reaction time.

Jonathan, Roberts & Martha Ann Bell (2003) compared Thirty-two college students16 male, 16 female had EEG recorded during computerized two- and three-dimensional mental rotation tasks. The simple two-dimensional mental rotation task was associated with more left parietal than right parietal activation in men and more right parietal than left parietal activation in women. The complex three-dimensional mental rotation task was associated with greater right parietal than left parietal activation in both men and women. Men performed better than women on the three-dimensional task and there were no differences between men and women on the two-dimensional task. It was concluded that men and women may be using different neurological strategies on two- and three-dimensional mental rotation tasks.

Shepard & Metzler (1971) in their mental imagery researchers showed that reaction times to recognize same shape pairs were a linear function of the degree of rotation of one object relative to the other, suggesting that participants mentally rotated an image of one of the stimuli until it came into congruence with the other. These and similar studies have been carried out with sighted participants but, as Paivio (1986) points out, imagery can be derived from all the sensory modalities and therefore even congenitally blind people could, in principle, form mental images of objects based on their intact sensory modalities.

Patricia, Carpenter & Peter Eisenberg (1978) investigated that the mental rotation in the congenitally blind with a haptic letter-judgment task. Blind subjects and blindfolded, sighted subjects were presented a letter in some orientation between 0° to 300° from upright and timed while they judged whether it was a normal or mirror-image letter. Both groups showed an increasing response time with the stimulus's departure from upright; this result was interpreted as reflecting the process of mental rotation. The results for the blind subjects suggest that mental rotation can operate on a spatial representation that does not have any specifically visual components. Further research showed that for the sighted subjects in the haptic task, the orientation of a letter is coded with respect to the position of the hand. Sighted subjects may code the orientation of the letter and then translate this code into a visual representation, or they may use a spatial representation that is not specifically visual.

Marmor & Zaback (1976) & Carpenter & Eisenberg (1978) compared that congenitally blind and blind-folded sighted participants with variants of Shepard and Metzler's (1971) mental rotation task. Both studies found the same relation between reaction time and angular disparity of the target shape as in the original experiment. In both studies, visually impaired and sighted participants reported mentally rotating, moving or twisting the target shape until it was aligned with the standard shape.

However, Marmor and Zaback also reported faster overall reaction times and lower error rates for the sighted participants. This suggests that, while congenitally blind people do form mental images which are functionally equivalent to those of the sighted, visual images may be easier to operate upon than haptic images. In the Carpenter and Eisenberg study, on the other hand, no differences were found between congenitally blind and sighted participants in errors or reaction times. The authors suggest that this discrepancy may have been due to the congenitally blind participants' previous experience with tactile graphic material.

Millar (1976) presented that the totally blind and blind-folded sighted children (aged 7 to 11 years) with a number of simple mental rotation tasks. The visually impaired children performed worse than the sighted children overall. From an analysis of the error scores Millar concluded that none of the children used external reference systems to solve the task resulting in low performance overall. The totally blind children could only accurately code rotations to orientations which were orthogonal to their own body co-ordinates. Millar suggests that young visually impaired children should be presented with tasks which encourage them to use more complex and flexible systems of reference.

Millar (1974; 1975; 1976; 1979; 1981) In Millar's (1979) studied the visually impaired children were required to reproduce an arrangement of four objects which were placed at the corners of either a square or a diamond shaped base. The original array was always present, and the children were required to reproduce it by moving all the objects onto a second identical base in one of two conditions. In the first condition, both bases were placed directly in front of the children with the second base further away. In the second condition, the bases were placed on either side of the children's mid-line. High errors by the totally congenitally blind group in the cross mid-line condition, but not in the vertical condition, suggested that that group were using a self-referent coding strategy. Qualitative analysis of the errors added support to this interpretation, showing that, in the cross mid-line condition, the totally congenitally blind group often reproduced the array as a mirror image. objects closer to the participants' mid-line in the original array were placed close to the mid-line in the reproduced array, while those further from the mid-line were placed further away.

Hollins & Kelley (1988) compared the early blinded and blind-folded sighted adults to learn the positions of five objects presented one by one on a circular table (91 cm diameter). Participants were then required either to aim a pointer at the locations of all the objects or to replace each one in its original position. These responses were made either from the position at which the objects had been examined or from a position 90˚ round the table. The visually impaired groups were less accurate than the blind-folded group when making pointer responses from a novel position, but there were no differences between groups when participants pointed to the objects' locations from the position from which they had been explored. Nor were there any differences between groups when participants replaced objects from either the original or the novel position. However, an analysis of the participants' patterns of errors suggested that the visually impaired group tended to "foreshorten" the locations of objects on the table; distant objects were imagined as being closer to the position at which the participant had originally explored the layout. Therefore, Hollins and Kelley suggested that the visually impaired participants felt the distances of objects from their own position which they used as a cue when learning the locations of objects. This cue was subsequently available to them to guide them in the replacement condition (where foreshortening was not observed) but was not available in the pointing condition when participants were asked not to reach out onto the table top.

Damaris Baena-Gomez, LoïcDeschamps, & Katia Rovira (2011) observed blind persons in a situation of mental rotation, it is more usual to emphasize their lack of visual experience than their expertise concerning tactile exploration. Nevertheless, it seems important to verify whether the procedures of tactile exploration developed by young blind persons enable them to recognize a shape whatever its orientation in space. Objective: The objective of this study was to compare blind adolescents and sighted adolescents in a situation of mental rotation, with raised patterns. Method: In this perspective, a group of blind adolescents and a group of sighted adolescents - matched for age and sex - have been observed during two task of mental rotation. Results: The results show that the blind adolescents are always faster, and they perform better when the rotation task concerns simple shapes. A fine analysis of the strategies of tactile exploration deployed by the subjects allows us to identify several procedures that are specific to the blind adolescents. These exploratory procedures allow them to compensate for the lack of visual experience, up to a certain level of complexity in the shapes. Conclusion: These results suggest that the recognition of 2D shapes after rotation in space is not necessarily problematic for the blind. These results are discussed in relation with recent work on the haptic competence of blind persons.

Robin & Pêcheux (1976) investigated the ability to reproduce two-dimensional and three-dimensional spatial models was tested in eighteen blind children, aged seven to eleven with two tasks (block design test and stick test). Performances and strategies were compared with those of seeing children. The results failed to show any important specific errors in blind children; despite blindness some children reached levels of performance as well as those of seeing children, while others completely failed to follow instructions. All such effects were independent of age. The problem is raised of the psychological conditions of space representation, independent of the inferences through which space is perceived.

Kerr (1983) showed in a mental exploration task that a strong relationship existed between the duration of mental exploration of distances and the distance to be covered, for persons who were sighted as well as those who were blind; these durations, though, were longer for congenitally blind persons than for those who became blind later in their lives. It seemed, therefore, that blind persons could create and manipulate spatial representations just as could sighted ones, but that visual experience allowed faster generation and treatment of images. However, these results were questioned by Röder and Rösler (1998). These researchers presented a task of mental distance exploration to congenitally blind adults, together with a phase in which participants learned spatial representation through tactile exploration. No difference between the two groups was evident. In a mental rotation task, Marmor and Zaback (1976) observed that the response times of participants who became blind early in life, those who became blind later in life, and of blind-folded sighted ones improved linearly as a function of the angle of rotation. However, for the participants who became blind early in life, response times were longer and errors more frequent than for the other two groups. Similarly, Carpenter and Eisenberg (1978) found a linear improvement of response times as a function of rotation, with congenitally blind participants slower (59° per second) than those who became blind later in life (114° per second) or blind-folded sighted (233° per second) participants. But the error rate was not different for the three groups, a result confirmed by Dodds, Howarth, and Carter (1982).

2.5.3 Rotational Displacement

Hughes & Santos (2012) investigated Rotational Displacement tasks, in which participants must track an object at a hiding location within an array while the array rotates, exhibit a puzzling developmental pattern in humans. Human children take an unusually long time to master this task and tend to solve rotational problems through the use of non-geometric features or landmarks as opposed to other kinds of spatial cues. They investigated whether these developmental characteristics are unique to humans by testing rotational displacement skills in a monkey species, the rhesus macaque (*Macaca mulatta*), using a looking-time method. Monkeys first saw food hidden in two differently colored boxes within an array. The array was then rotated 180° and the boxes reopened to reveal the food in an expected or unexpected location. Our first two experiments explored the developmental time-course of performance on this rotational displacement task. They found that adult macaques looked longer at the unexpected event, but such performance was not mirrored in younger-aged macaques. In a third study, they systematically varied featural information and visible access to the array to investigate which strategies adult macaques used in solving rotational displacements. Our results show that adult macaques need both sets of information to solve the task. Taken together, these results suggest both similarities and differences in mechanisms by which human and nonhuman primates develop this spatial skill.

2.5.4 Mental Imagery and Spatial Imagery

David Dulin & Yvette Hatwell (2012) evaluated the impact of instruction in raised-line drawings on the spatial imagery capacity of congenitally and late blind people. The participants first performed preliminary tasks in order to evaluate their individual level of experience in the recognition and production of raised-line drawings. Then, all the participants (experienced congenitally and late blind groups, non-experienced congenitally and late blind groups, and blind-folded sighted participants) were presented with a mental rotation task, a mental spatial displacement task, and a direction judgment task. After this pre-test, half of the non-experienced participants (congenitally and late blind) were trained for 6 months in the recognition and production of raised-line drawings. Then, all the groups were presented again with the 3 spatial tasks (post-test). Results showed that the experienced participants performed better than the non-experienced ones in all the spatial imagery tasks of the pre-test. Contrary to the non-trained participants, the trained participants improved their skills as revealed during the post-test, and they performed as well as the non-trained experienced blind groups on all the spatial tasks of the post-test. These data indicate that a short yet intensive training of the blind people had a significant effect and that the benefits generalize to other spatial tasks (i.e., mental rotation, mental spatial displacement, and direction judgment tasks). In addition to a better understanding of blind people's cognitive functioning, these results may have important implications regarding the value of line drawing training in the education of visually impaired people.

Cooper & Shepard (1973) this study was an early concern for mental imagery, but problems with that research led to the virtual abandonment of the study of imagery. More recently, researchers have found ways to measure certain aspects of imagery. One successful technique uses “rotation” of mental images. A person is shown two shapes and must decide whether or not they are the same (regardless of rotation). One shape is sometimes rotated with respect to the other, and people report that they make the judgment by rotating their image of one shape to determine whether it matches the other. If people’s reports are accurate, it should take longer to rotate the image when the stimulus is rotated farther from vertical. Shepard and other colleagues have done a number of experiments of this type, and have found that images do seem to be rotated, and at a steady, measurable speed. The exercise accompanying this chapter has students perform one of two versions of this task to measure the speed of rotation of mental images.

Annick Vanlierde & Marie-Chantal Wanet-Defalque (2005) compared mental imagery of participants who became blind early in life (EB participants), participants who became blind later in life (LB participants), and sighted participants was compared in two experiments. In the first experiment, the participants were asked to image common objects and to estimate how far away these objects appeared in their image. In the second experiment, the participants were asked to point to the left and right sides of three objects, imaged at three increasing distances. The LB participants' performance of the tasks in both experiments was similar to that of the sighted participants, whereas the performance of the EB participants differed. The results reflect the close relationship between the development of visual perception and the properties of images.

Matthi & Albertpostma (2006) compared between blind and sighted participants on a visual-imagery and a spatial-imagery task, but not on an auditory-imagery task. For the visual-imagery task, participants had to compare object forms on the basis of a (verbally presented) object name. In the spatial-imagery task, they had to compare angular differences on the basis of the position of clock hands on two clock faces, again only on the basis of verbally presented clock times. Interestingly, there was a difference between early-blind and late-blind participants on the visual-imagery and the spatial-imagery tasks: late-blind participants made more errors than sighted people on the visual-imagery task, while early-blind participants made more errors than sighted people on the spatial-imagery task. This difference suggests that, for visual (form) imagery, people use the channel currently available (haptic for the blind; visual for the sighted). For the spatial-imagery task in this study reliance on haptic processing did not seem to suffice, and people benefited from visual experience and ability. However, the difference on the spatial-imagery task between early-blind and sighted people in this study might also be caused by differences in experience with the analogue clock faces that formed the basis for the spatial judgments.

Gaunet & Thinus-Blanc (1996) studied that the ability of blind and blind-folded sighted adults to localize objects in small- and large-scale spaces, and observed some limitation of the capacity for mental imagery in the blind participants. The place of one object was changed between presentation and test phases, and participants were asked to detect this change. Results showed that the exchange of places between two objects (topological change) was equally well detected by all participants, whereas the displacement of an object in centimeters (metrical change) was less well detected by those who were congenitally blind.

Gandhi, Ganesh & Sinha (2014) explored that the factors contributing to the development of spatial imagery skills are not well understood. Here they ask whether visual experience shapes these skills. Although differences between sighted and the blind on spatial imagery have been reported, it is unclear whether they are truly due to visual deprivation or extraneous factors such as reduced opportunities for the blind to interact with their environment. A direct way of assessing vision's contribution to spatial imagery development lies in determining whether these skills change soon after the onset of sight in a congenitally blind individual. We describe our results with ten children who gained sight after several years of congenital blindness. We find significant improvements in their spatial imagery skills following sight-restoring surgeries. These results provide evidence of vision's contribution to spatial imagery and also have implications for the nature of internal spatial representations.

Levine, Ratliff, Huttenlocher, & Joanna Cannon (2011) examined the relation between children's early puzzle play and their spatial skill. Children and parents (*n* _ 53) were observed at home for 90 min every 4 months (6 times) between 2 and 4 years of age (26 to 46 months). When children were 4 years 6 months old, they completed a spatial task involving mental transformations of 2-dimensional shapes. Children who were observed playing with puzzles performed better on this task than those who did not, controlling for parent education, income, and overall parent word types. Moreover, among those children who played with puzzles, frequency of puzzle play predicted performance on the spatial transformation task. Although the frequency of puzzle play did not differ for boys and girls, the quality of puzzle play (a composite of puzzle difficulty, parent engagement, and parent spatial language) was higher for boys than for girls. In addition, variation in puzzle play quality predicted performance on the spatial transformation task for girls but not for boys. Implications of these findings as well as future directions for research on the role of puzzle play in the development of spatial skill are discussed.

2.6 Spatial Knowledge among Young Children

Morrongiello, Timney, Humphrey, Anderson, & Skory (1995) showed that the spatial knowledge was evaluated in sighted and congenitally blind children using a large-scale four-location navigation task adapted from the work of Landau, Spelke, and Gleitman (1984). From video records they coded the exact path taken and determined accuracy of initial turn, closest position, and final position, relative to target location. They then computed a score to index the efficiency of the path taken. For the sighted sample, after the navigation task, children constructed a tactile map of the test space without the aid of vision and, following removal of the blindfold drew from memory the spatial layout of the test space. Performance on the navigation and mapping tasks consistently indicated increasing cognitive mapping skills with age in sighted children. Blind children performed comparably to the sighted on all measures except accuracy at final position, for which their performance was worse than that of the sighted. Analysis of the directness of novel paths and other measures taken suggest caution in ascribing well developed Euclidean coding skills to very young children. Results are discussed in light of Landau et al.'s (1984) conclusions.

Barbara Landau, Elizabeth Spelke, & Henry Gleitman (1984) used a set of eight experiments to demonstrate spatial knowledge in a 2-year-old congenitally blind child and sighted blind-folded controls. Once the blind child had traveled along specific paths between objects in a novel array, they were able to make spatial inferences, finding new routes between those objects (Experiment 1). They could also do so when the routes were between places in space, not occupied by objects (Experiment II). Deviations from precisely straight routes in Experiments I and II were not due to faulty inferences, but probably came from imprecise motor control, since the same deviations occurred when inferences were not required-when the child moved to a place designated by a sound source (Experiment III). This child's performances could not be accounted for by art factual explanations: sound cues, experimenter bias, and echolocation were ruled out (Experiments IV, V, VI). Further, sighted blind-folded controls performed at roughly the same level (Experiment VII). Finally, Experiment VIII shows that the blind child could access her spatial knowledge for use in a simple map-reading task. They conclude that the young blind child has a system of spatial knowledge, including abstract, a modal rules.

Bigelow (1996) found that the development of spatial knowledge of the home environment was longitudinally studied in three groups of school-age children who varied in their visual ability: totally blind, visually impaired, and normally sighted.

The children were asked to judge who of three locations in their homes was the closest to a designated position: (1) judging by the routes necessary to get to the locations; and (2) judging by straight-line distances to the locations. Locations were either on the same floor as the designed position, on a different floor, or in the yard. Totally blind children were delayed in mastery of the tasks compared to the other children, particularly in judging straight-line distances between familiar locations. Their mistakes suggest that their spatial understanding of their home environments is based on their knowledge of routes between places rather than on their knowledge of the overall layout of the familiar space.

John, Riser, Jeffrey, Lockman, Herbert, & Pick, (1980) found that adventitiously blinded. congenitally blind, and sighted adults made relative distance judgments in a familiar environment under three sets of instructions-neutral with respect to the metric of comparison, Euclidean (straight-line distance between landmarks), and functional (walking distance between landmarks). Analysis of error scores and multidimensional scaling procedures indicated that, although there were no significant differences among groups under functional instructions, all three groups differed from one another under Euclidean instructions. Specifically, the sighted group performed best and the congenitally blind group worst, with the adventitiously blind group in between. The results are discussed in the context of the role of visual experience in spatial representation and the application of these methods for evaluating orientation and mobility training for the blind.

Anthony, Richardson, Daniel, Montello, & Mary Hegarty (1999) investigated the nature of the spatial representations of an environment acquired from maps, navigation, and virtual environments (VE) was assessed. Participants first learned the layout of a simple desktop VE and then were tested in that environment. Then, participants learned two floors of a complex building in one of three learning conditions: from a map, from direct experience, or by traversing through a virtual rendition of the building. Virtual environments learners showed the poorest learning of the complex environment overall, and the results suggest that virtual environments learners are particularly susceptible to dis-orientation after rotation. All the conditions showed similar levels of performance in learning the layout of landmarks on a single floor. Consistent with previous research, an alignment effect was present for map learners, suggesting that they had formed an orientation-specific representation of the environment. Virtual environments learners also showed a preferred orientation, as defined by their initial orientation when learning the environment. Learning the initial simple virtual environments was highly predictive of learning a real environment, suggesting that similar cognitive mechanisms are involved in the two learning situations.

Konstantinos Papadopoulos, Eleni Koustriava, & Lefkothea Kartasidou (2011) described the Loss of vision is believed to have a great impact on the acquisition of spatial knowledge. The aims of the present study are to examine the performance of individuals with visual impairments on spatial tasks and the impact of residual vision on processing these tasks. In all, 28 individuals with visual impairments-blindness or low vision-participated in this study. The results reveal that participants with visual impairments were competent to perform spatial tasks, and their performance is related to the existence of residual vision.

2.7 Spatial Cognition and the Brain

Neil Burgess (2008) conducted a study focusing on memory for locations in large-scale space and on those advances inspired by single-unit recording and lesion studies in animals. Spatial memory appears to be supported by multiple parallel representations, including egocentric and allocentric representations, and those updated to accommodate self motion. The effects of these representations can be dissociated behaviorally, developmentally, and in terms of their neural bases. It is now becoming possible to construct a mechanistic neural-level model of at least some aspects of spatial memory and imagery, with the hippocampus and medial temporal lobe providing allocentric environmental representations, the parietal lobe egocentric representations, and the retros plenial cortex and parieto-occipital sulcus allowing both types of representation to interact. Insights from this model include a common mechanism for the construction of spatial scenes in the service of both imagery and episodic retrieval and a role for the remainder of Papez’s circuit in orienting the viewpoint used. In addition, it appears that hippocampal and striatal systems process different aspects of environmental layout (boundaries and local landmarks, respectively) and do so using different learning rules.

Marina Vasilyeva1 & Lourenco (2012) explored Spatial cognition plays an essential role in everyday functioning and provides a foundation for successful performance in scientific and technological fields. Reasoning about space involves processing information about distance, angles, and direction. Starting from infancy, children display sensitivity to these spatial properties, although their initial skills are quite limited. Subsequent development during early childhood and through the elementary school years involves gradual improvement in the use of individual frames of reference (i.e., egocentric and allocentric), as well as in the ability to flexibly combine different types of spatial information. Similarly, there is a relatively long progression from the starting points, when infants and young children display sensitivity to distance and form simple spatial categories, to more mature spatial competence when older children and adults integrate distance and categorical information hierarchically. Such developments are associated with both the maturation of specific brain regions and accumulating experience, including interactions with the physical world and the acquisition of cultural tools. In particular, the mastery of symbolic spatial representations, such as maps and models, significantly augments basic spatial capabilities. While growing evidence implicates both biological and experiential factors in the development of spatial cognition, a deeper understanding of the mechanisms that underlie the developmental process requires further investigation of how such factors interact to produce organisms that function competently in their environments.

Spatial processing skills are an important component in cognitive development. It has been shown that there are many students who, because of their perceptual differences could use assistance in developing spatial concepts and relationships through experience in multi-perceptual alternative learning environments. Virtual reality has potential as a setting for multi-perceptual, experiential learning. This study evaluates the effect of designing and experiencing a virtual world as a spatial processing skill enhancement method, and as an aid to cognitive development.

Dan Jacobson (1998) illustrated the application of cognitive mapping to people with visual impairments and blindness. It gives perspectives on past research, outlines ongoing research, highlights some of the methodological and validity issues arising from this research, and discusses the movement of theory into practice. The findings of three small preliminary studies have been reported, as part of continuing research into the cognitive mapping abilities of blind or visually impaired people. These studies have highlighted the need to use multiple, mutually supportive tests to assess cognitive map knowledge. In light of these findings and the need to move theory into practice, a current research project is outlined. This project seeks to use the knowledge gained from the three projects to design and implement an auditory hyper map system to aid way finding and the spatial learning of an area. Finally an agenda for applied research is presented.

Ken Sutton & Anthony Williams (2007) examined the performance of participants on a range of spatial cognition tasks considered important to designers. It also provides evidence that helps validate a new psychometric test developed to measure spatial concepts represented in technical drawings. Participants were university students divided into a skilled group and an unskilled group based on whether or not they had prior technical drawing experience. The skilled group did consistently better on spatial ability tasks with differences in performance shown to be statistically significant. Tasks requiring advanced spatial skills associated with coordinate systems were found to be difficult. Other tasks requiring spatial reasoning to identify three dimensional properties from two-dimensional drawings produced better results than expected.

The paper concludes with an overview of implications for designers and technical drawing.

Orly Lahav & David Mioduser(2003) conducted mental mapping of spaces, and of the possible paths for navigating these spaces, is essential for the development of efficient orientation and mobility skills. Most of the information required for this mental mapping is gathered through the visual channel. Blind people lack this crucial information and in consequence face great difficulties (a) in generating efficient mental maps of spaces, and therefore (b) in navigating efficiently within these spaces.

The work reported in this paper follows the assumption that the supply of appropriate spatial information through compensatory sensorial channels, as an alternative to the (impaired) visual channel, may contribute to the mental mapping of spaces and consequently, to blind people's spatial performance. The main tool in the study was a virtual environment enabling blind people to learn about real life spaces, which they are required to navigate.

Simon Ungar, Mark Blades & Christopher Spencer (1996) showed that the way in which children who have visual impairments construct cognitive maps of their environment is of considerable theoretical and practical importance. It sheds light on the role of sensory experience in the development of spatial cognition which can in turn suggest how spatial skills might be nurtured in visually impaired children. In most of the studies reviewed here, groups of children who lost their sight early in life perform less well on a variety of spatial tasks than sighted children or children who lost their sight later in life. They will argue that it is not the lack of visual experience in itself which produces this pattern, but rather the effect of lack of vision on the spatial coding strategies adopted by the children. Finally they will discuss a number of methods for encouraging visually impaired children to use coding systems which are appropriate for the construction of flexible and integrated cognitive maps, with particular reference to the use of tactile maps.

2.8 Spatial Memory

Hollins & Kelley (1988) in their study made the participants stood behind a circular table and haptically explored five objects presented successively, after which they were asked to memorize the location of each object separately. The test consisted of the participant syndicating with a pointer the direction of each of the five objects from the original place and then from a new pointing place elsewhere on the table. Pointing errors were greater for congenitally blind participants from the new pointing place, but their performances rose to those of sighted participants when they were asked to actually replace the object on the table. These results were explained by an examination of the nature of the errors committed by congenitally blind participants. They represent geometric features appeared globally distorted because the size of the table was minimized. This distortion explains pointing errors. In contrast, while replacing the object, the participants touched the table. That allowed the congenitally blind participants to restore the metric relations between the set of objects and the table on which the objects were displayed.

Loomis et al. (1993) involved congenitally, late blind, and blind-folded sighted participants on a series of tests of varying complexity. The participants were led by an experimenter along pathways that were either straight or involved turns of various amplitudes. They were asked to reproduce the pathways without using an aid. The angular estimation of the turns was also performed by the participants using a pointer. No group differences in performance were found as a function of visual experience. In other similar experiments where participants were required to learn a route no differences were found in relation to the time of onset of blindness.

Rieser et al. (1986) evaluated the effect of early blindness on spatial memory. The participants were guided from a place (start) to six other locations, marked by objects, in an unfamiliar environment. After each visit from the start to one of the six places, the participant was returned to the start (see Figure 1). Spatial memory tests consisted of the participants pointing from the start toward the places to which they had been led. Rieser et al. found no differences between the groups in the accuracy of direction evaluations (by pointing) and in latencies of spatial memory tests. Altogether these data demonstrate that early or congenital blindness has little or no effect on direction and distance estimation of spatial relationships among locations that have been actually visited by the participants or explored with their fingers. In this respect, Lederman, Klatzky, and Barber (1985) suggested the possibility that early blind people use "heuristics," based on exploration movements which may result in the representation of a route Bigelow 1991.

Millar (1975) investigated in spatial memory by blind and sighted children. Experimenter showed that Non-verbal recall of haptically presented spatial positions by three age groups of blind and sighted children was tested under conditions varying cueing; recall type and stimulus position in a within-subject design. Sighted status was not only significant, but interacted significantly with recall type, and further with stimulus position, consistent with sequential haptic by blind and quasi-simultaneous visual processing by sighted children. Age was significant, but its only significant interaction was a relatively small one with cueing conditions and stimulus position, suggesting that the oldest group, regardless of sightedness, used verbal strategies in pre-cued conditions. The findings support the hypothesis that visual and haptic modalities of representation have demonstrably different effects on processing and efficiency in spatial recall, but counter indicate the hypothesis that these relate differentially to age. Results also suggest that a combination of cue utilization and verbal strategies is a significant, but relatively minor, factor in improvements in spatial recall.

Scarr, Cockburn & Gutwin (2013) found that Spatial Memory in User Interfaces. Spatial memory is an important facet of human cognition - it allows users to learn the locations of items over time and retrieve them with little effort. In human-computer interfaces, knowledge of the spatial location of controls can enable a user to interact fluidly and efficiently, without needing to perform slow visual search. Computer interfaces should therefore be designed to provide support for developing the user's spatial memory, and they should allow the user to exploit it for rapid interaction whenever possible. However, existing systems offer varying support for spatial memory. Many break the user's ability to remember spatial locations, by moving or re-arranging items; others leave spatial memory underutilized, requiring slow sequences of mechanical actions to select items rather than exploiting users' strong ability to index items and controls by their on-screen locations. The aim of this paper is to highlight the importance of designing for spatial memory in HCI. Examine the literature using an abstract-to-concrete approach. First, they identify important psychological models that underpin our understanding of spatial memory, and differentiate between navigation and object-location memory (with this review focusing on the latter). They then summarise empirical results on spatial memory from both the psychology and HCI domains, identifying a set of observable properties of spatial memory that can be used to inform design. Finally, they analyze existing interfaces in the HCI literature that support or disrupt spatial memory, including space-multiplexed displays for command and navigation interfaces, different techniques for dealing with large spatial data sets, and the effects of spatial distortion. They intend for this paper to be useful to user interface designers, as well as other HCI researchers interested in spatial memory. Throughout the text, they therefore emphasise important design guidelines derived from the work reviewed, as well as methodological issues and topics for future research.

2.9 Tactual Recognition

Heller, Calcaterra, Burson, & Tyler (1996) in their four experiments examined the influence of categorical information and visual experience on the identification of tangible pictures, produced with a raised-line drawing kit. In Experiment 1, prior categorical information aided to accuracy and speed of picture identification. In a second experiment, categorical information helped subjects when given after the examination of each picture, but before any attempt at identification. The benefits of categorical information were also obtained in another group of subjects, when the super ordinate categories were named at the start of the experiment. In a third experiment, a multiple-choice picture recognition task was used to eliminate the difficulty of naming from the picture-identification task. The multiple-choice data showed higher accuracy and shorter latencies when compared with identification tasks. A fourth experiment evaluated picture identification in blind-folded sighted, early, and late blind participants. Congenitally blind subjects showed lower performance than did the other groups, despite the availability of prior categorical information. The data were consistent with theories that assume that visual imagery aids tactual perception in naming raised line drawings. It was proposed that part of the difficulty in identification of raised line pictures may derive from problems in locating picture categories or names, and not merely in perception of the patterns.

Morrongiello, Humphrey, Timney, Choi, & Rocca (1994) evaluated by examining object exploration and recognition in sighted children between the ages of 3 and 8 years. To determine the importance of visual experience for these abilities, the performance of seven congenitally blind children was compared with that of sighted peers matched for age and gender. Performance was evaluated in terms of the speed and correctness of object identification, thoroughness of exploration of object parts, representation of the global form versus local parts of objects, and the possible role of critical parts in object identification. Four types of common objects were presented: normal-sized, miniaturized small, miniaturized large and oversized objects. All subjects were required to manipulate and identify these objects haptically, without the aid of vision. Results revealed the emergence of a developmental pattern in all performance measures for sighted children. Older sighted children were not only able to recognize more objects and to do so more quickly, but also were more thorough in their exploration patterns. With increasing age, children appear to change their representation of objects from one based predominantly on global shape to one that incorporates a balance of global shape and specific local parts. In agreement with this, critical parts also played a role in object identification, particularly in older children. Blind and sighted children did not differ in any performance measures, which suggests that previous visual experiences do not determine tactile exploration strategies and are not essential for haptic object recognition.

Magdalena Szubielska (2015) observed on the recognition of tactile figures by blind and sighted individuals. The findings allow the conclusion that, while visualizing shapes explored by touch, sighted individuals retain the size of the objects in their working memory and while comparing figures of various sizes they perform the process of mental scaling. By contrast, the size of objects does not seem to be of significance in mental representations created by blind individuals.

Malgorzata Toroj (2011) described the role of prior visual experience for tactile differentiation of object shapes. The study investigated whether people who lost their vision later in life were able to identify and recognize object shapes more accurately and faster than those who were blind from their birth. Four experiments were conducted. The first two were concerned with tactile shape *differentiation*, the second two with shape *recognition*. The hypotheses were only partially confirmed. The ‘late’ blind participants distinguished shapes more accurately than the congenitally blind (particularly in ‘simple’ perception tasks). This finding may suggest that people who have prior visual experience use an allocentric strategy when visualizing object shapes in their imagery. The ‘late’ blind participants performed the tasks more slowly than those who were congenitally blind. This may be explained by the complexity of the task, the time needed to create an allocentric representation, and discrepancy in the tactile experiences between the congenitally and late blind groups. A number of implications for further research are outlined.

Sunanto & Nakata (1998) compared the ability of blind and blind-folded sighted subjects to discriminate cubes of different heights was measured using the method of constant stimuli. Five male blind and 5 male blind-folded sighted students, ages 22 to 28 years, were subjects. All blind subjects had undergone orientation and mobility training at a school for the blind. The cubes, made of wood, were explored using a long cane. Subjects were presented the standard cube and a comparison cube and required to judge whether the comparison cube height was taller, the same, or shorter than the standard. Analysis showed that the difference thresholds of blind and blind-folded sighted subjects were 1.93 and 2.14 cm, respectively. No significant difference in accuracy of discrimination was found between the two groups. The blind subjects showed significantly better performance than the blind-folded sighted subjects on the discrimination task. The blind subjects performed the task significantly faster than the blind-folded sighted subjects. The results suggest that Braille reading, use of a long cane, and daily physical activities which required prolonged haptic or proprioceptive learning, may enhance non-visual motor skills.

Pathak & Pring (1989) carried out the basic experiments to investigate tactual processing of two-dimensional raised line drawings by blind and blind-folded sighted children. The results showed an unexpected but consistent pattern indicating that the introduction of 'meaning' facilitated the performance of the blind-folded sighted children but caused a relative decline in the performance of the congenitally blind. A general lack of evidence distinguishing between recognition of objects that had or had not been directly experienced through touch suggested that the internal spatial representations of objects depended not only on perceptual information but also on knowledge derived from other sources.

Postma, Zuidhoek, Noordzij, & Kappers (2008) presented Early-blind, late-blind, and blind-folded sighted participants with two haptic allocentric spatial tasks: a parallel-setting task, in an immediate and a 10-sec delay condition, and a task in which the orientation of a single bar was judged verbally. With respect to deviation size, the data suggest that mental visual processing filled a beneficial role in both tasks. In the parallel-setting task, the early blind performed more variably and showed no improvement with delay, whereas the late blind did improve, but less than the sighted did. In the verbal judgment task, both early- and late-blind participants displayed larger deviations than the sighted controls. Differences between the groups were absent or much weaker with respect to the haptic oblique effect, a finding that reinforces the view that this effect is not of visual origin. The role of visual processing mechanisms and visual experience in haptic spatial tasks is discussed.

Kappers & Koenderink (1999) investigated the haptic perception of spatial relations in a systematic way. They restricted themselves to a horizontal plane at waist height. Blind-folded subjects were asked to perform three tasks with their right hand: (i) a reference bar was presented under four different orientations and subjects were asked to rotate a test bar such that it felt to be parallel to the reference bar; (ii) subjects had to rotate two test bars in such a way that they felt collinear; (iii) subjects had to point a test bar in the direction of a marker. Bars and marker could appear at nine different locations. In all experiments large systematic deviations (up to 408) were made. The deviations strongly correlated with horizontal (right ^ left) but not with vertical (forward ^ backward) distance. Subjects showed qualitatively identical trends but the size of the deviations was strongly subject-dependent. In addition, a significant haptic oblique effect was found. These results provide strong evidence that haptic space in non-Euclidean.

2.10 Spatial Language

Loomis, Lippa, & Klatzky (2002) compared the Blind and blind-folded sighted observers with auditory stimuli specifying target locations. The stimulus was either sound from a loudspeaker or spatial language. On each trial, an observer attempted to walk to the target location along a direct or indirect path. The ability to mentally keep track of the target location without concurrent perceptual information about it (spatial updating) was assessed in terms of the separation between the stopping points for the 2 paths. Updating performance was very nearly the same for the 2 modalities, indicating that once an internal representation of a location has been determined, subsequent updating performance is nearly independent of the modality used to specify the representation.

Hayward & Tarr (1995) explored commonalities between linguistic and visual representations of space. In particular, because common types of spatial relations, specifically closed-class spatial forms in language and qualitative spatial relations in perception, have been proposed in both representational systems, they investigate whether they share underlying structural similarities. Visual spatial relations are a basic element of several theories of object representation; they have been characterized mainly in terms of their linguistic counterparts and without direct evidence about their organization. Compare how the spatial relationship between pairs of objects in a scene is encoded linguistically and visually. Spatial language was investigated by having subjects either generate (Experiment 1) or rate the applicability of (Experiment 2) spatial terms for describing the spatial relationship between object pairs. Both the frequency of use and the applicability of spatial terms were highest when the two objects were in vertical or in horizontal alignment. Spatial representation was investigated by paradigms in which subjects either recalled the position of one object relative to the other (Experiment 3) or judged whether one object presented sequentially was in the same or a different position relative to the other (Experiment 4). The accuracy of position estimates and the sensitivity to shifts in position were both highest when the rated object was in a spatial location where spatial terms had been judged to have high applicability in Experiments 1 and 2. These results indicate that the structure of space as encoded by language may be determined by the structure of spatial relations in visual representation.

Cite this article as (2014) carried out a study on the development of geocentric spatial cognition with 4-14 year old children of Hindi and Sanskrit medium schools. A number of tasks and procedures were used to assess the spatial frames of reference children used in describing and interpreting spatial displays. Analysis revealed that Sanskrit medium school children used more geocentric language and encoding than Hindi medium school children. The effect of age was significant only for encoding, not for language. Geocentric spatial cognition was significantly linked to fundamental spatial cognitive ability, as measured by Story-Pictorial Embedded Figures Test and Block Designs Test. The stronger expression of geocentric language and geocentric encoding in Sanskrit than Hindi medium school children suggests that the use of the ability can be sharpened by its practice and actualization in day-to-day life. The relationship between language and encoding was found to be of a moderate level suggesting that geocentric cognition is not determined by language alone, but also by other factors present in children's eco-cultural contexts.

2.11 Spatial Orientation

Maria Kozhevnikov & Mary Hegarty (2001) investigated that the Spatial orientation ability, is the people are shown a two dimensional array of objects, imagine taking a perspective within the array, and indicate the direction to a target object from this perspective. Patterns of errors on these tests were consistent with experimental studies of perspective taking. Characteristic errors and verbal protocols supported the validity of the perspective-taking tests, suggesting that people encoded the objects in the display with respect to a body-centered coordinate system when the imagined perspective was more than 90º different from the orientation of the display. By comparing alternative models in a confirmatory factor analysis, we found that the ability to mentally rotate and manipulate an imagined object (as measured by tests of spatial visualization and spatial relations) and the ability to reorient the imagined self (as measured by the perspective-taking tests) are separable spatial abilities.

Carpenter & Just (1986) Carroll (1993) found that the majority of participants reported a mental rotation strategy on the Guilford-Zimmerman task. This would account for its typically high loading on the spatial visualization factor (Carroll, 1993). They suggest that the failure to find a distinction between object manipulation and spatial orientation abilities in the psychometric literature occurs because there are currently no pure psychometric tests of spatial orientation ability. The participants were 71 undergraduate students recruited from the psychology subject pool at the University of California, Santa Barbara. The materials consisted of seven paper-and-pencil tests of spatial abilities. Object manipulation abilities were assessed by using the Card Rotation Test, the Cube Comparison Test 2 and the Paper Folding Test (Ekstrom, French, & Harman, 1976). The Card Rotation Test requires participants to view a two-dimensional target figure and judge which of the five alternative test figures are planar rotations of the target figure (as opposed to its mirror image)as quickly and as accurately as possible. In the Cube Comparison Test, each item presents two drawings of cubes, with letters and numbers printed on their sides.

Participants must judge whether the two drawings could show the same cube. Items in the Paper Folding Test show drawings of two or three folds made in a square sheet of paper. The final drawing shows a hole being punched in the folded paper. The task is to select one of five drawings that shows how the punched sheet would appear when fully opened.

2.12 Gender Differences in Spatial Ability

David Tzuriel & Gila Egozi (2010) A sample of 116 children (M=6 years 7 months) in Grade 1 was randomly assigned to experimental (n=60) and control (n=56) groups, with equal numbers of boys and girls in each group. The experimental group received a program aimed at improving representation and transformation of visuospatial information, whereas the control group received a substitute program. All children were administered mental rotation tests before and after an intervention program and a Global-Local Processing Strategies test before the intervention. The results revealed that initial gender differences in spatial ability disappeared following treatment in the experimental but not in the control group. Gender differences were moderated by strategies used to process visuospatial information. Intervention and processing strategies were essential in reducing gender differences in spatial abilities.

Maartje de Goede (2009) studied the spatial abilities, such as wayfinding and memorizing object locations, seems to be equally important for every individual. Yet both common belief and scientific literature claim that men and women differ in these abilities. Whereas ‘spatial ability’ used to be considered as a unitary capacity, on which males would generally outperform females, this oversimplified view has been convincingly challenged during the past decades. Besides the fact that spatial cognition comprises a broad range of different skills, it is now acknowledged that gender differences in spatial performance strongly depend on the specific ability measured. While sub processes like mental rotation and spatial perception indeed show clear male advantages, the memorization of object locations often yields a females advantage. However, despite reasonably reliable findings with traditional paper-and-pencil tasks, findings on more real life activities are far less consistent. Understanding the key mechanisms requires the decomposition of these complex activities into their basic cognitive processes. The present thesis provides insight in some crucial task components- and conditions that can modulate gender differences in two important daily spatial abilities; object location memory and spatial navigation. On the one hand we have shown that controllable factors, such as task type, familiarity with an environment as well as different inclinations in males and females to focus on specific environmental cues, affect performance to solve particular spatial problems. Nevertheless, besides these situation specific gender effects, more hard-wired cognitive abilities seem to be involved as well, as is reflected for example in the consistent male advantage in mental rotation ability, as well as the demonstrated hormone-behaviour correlates. In addition to a better understanding of differences between male and female spatial cognitive behaviour, this research contributes to a more substantial comprehension of the various complex cognitive processes spatial abilities encompass.

Many researchers believe that substantial sex differences in spatial abilities do exist. However, researchers have not been able to claim that gender differences in spatial abilities exist across the entire range of sub-factors of spatial abilities. Instead, researchers have only been able to find sex differences in specific subdivisions of spatial ability. For example, Linn and Peterson (1985) reported a large gender difference in mental rotation tasks favoring males, and Alexander (2005) reported a gender difference in visual memory tasks favoring females.

Maccoby & Jacklin (1974) also made claims of gender differences using only one sub-factor of spatial abilities. They separated the field of spatial ability into two groups: non-visual and visual spatial abilities and then used the Embedded Figures Test to suggest that visual-spatial ability tests show sex differences favoring men. With researchers making claims of the existence of gender differences in spatial abilities, it seems only natural for other researchers to provide possible reasons for such differences. Brownlow et al. (2003) suggests that women’s poor performance on mental rotation tasks may be due to the knowledge of negative social stereotypes, which suggest that women perform less well on tests of spatial ability than men do.

Crawford et al. (1995) claimed that women are negatively influenced by identifying a test as a measure of their spatial ability. Specifically, when women are told that a task will be used to measure their spatial ability, their performance is worse than when they are not told anything about the purpose of the task. Crawford et al. (1995) also contend that this difference in spatial ability due to social stereotypes is evident even during childhood. They propose that the gender specific toys that are given to children engage different types of abilities from a very young age. For example, boys are often given blocks and LEGOS from which they are able to build models and structures from pictures and diagrams. In contrast, girls are often given dolls and Barbies which they are able to nurture but not manipulate. “Boy” toys seem to help engage and develop spatial abilities while “girl” toys do not. Thus, it seems natural to link men’s superior spatial ability to the lack of female experience and familiarity with spatial tasks.

Recently, Ginn & Pickens (2005) stated that previous research suggested that the male advantage on mental rotation tasks might be related to experience with spatial tasks. The study conducted by Ginn and Pickens (2005) examined whether participation in different types of spatial activities would affect women’s performance on mental rotation tasks. Ginn and Pickens administered a mental rotation test to 31 male and 59 female participants who were either enrolled in a music or art class or who participated in athletics at a local college. Ginn and Pickens found that women’s scores on the mental rotation test were affected by their participation in spatial activities. Women who participated in music, art, or athletics had more experience with spatial activities and scored higher on the mental rotation test than did women who did not participate in these activities. It seems that practice is an important factor affecting the existence of sex differences in spatial abilities.

There is considerable evidence supporting the existence of gender differences in spatial abilities; however, researchers have only been able to make claims of sex differences in specific subdivisions of spatial ability. Moreover, many claims have been made about possible social and environmental causes of sex differences in spatial abilities.

While many researchers contend that substantial sex differences in spatial abilities exist, an equal number of researchers maintain that substantial gender differences in spatial abilities do not exist. Researchers who challenge the notion of sex differences argue that the current research on sex differences in spatial ability is inconsistent and flawed. The most well-known paper supporting that evidence for sex differences is unreliable was written in 1985 by Caplan, MacPherson, & Tobin. Caplan et al. (1985) suggested that part of the reason for some of the inconsistency in research findings may be due to a lack of a clear and agreed upon definition for "spatial ability." Until a universal definition for the construct of spatial ability is developed, researchers will not too able to reach a consensus concerning the existence of sex differences in spatial abilities according to the authors. Moreover, Caplan et al. (1985) claimed that experimental tests are often erroneously categorized as measures of spatial ability and then used to describe inaccurate conclusions regarding gender differences in spatial ability, when the tests are not actual measures of spatial abilities. Caplan et al. (1985) also suggested that results drawn from many studies are often over-generalized. For explain, single-test studies are used to draw overall conclusions regarding sex differences in spatial abilities.

While some researchers make claims about possible environmental causes for gender differences in spatial abilities, Lohman (1986) maintained that gender differences in spatial abilities can be eliminated with exposure and practice. Thus, he believed that if female children or adults are given ample opportunity to practice a spatial task, no gender difference will exist.

Scott Barry Kaufman (2006) studied sex differences in spatial ability are well documented, but poorly understood. In order to see whether working memory is an important factor in these differences, 50 males and 50 females performed tests of three-dimensional mental rotation and spatial visualization, along with tests of spatial and verbal working memory. Substantial differences were found on all spatial ability and spatial working memory tests (that included both a spatial and verbal processing component). No significant differences were found in spatial short-term memory or verbal working memory. In addition, spatial working memory completely mediated the relationship between sex and spatial ability, but there was also a direct effect of sex on the unique variance in three-dimensional rotation ability, and this effect was not mediated by spatial working memory. Results are discussed in the context of research on working memory and intelligence in general, and sex differences in spatial ability more specifically.

Levine, Janellen Huttenlocher, Amy Taylor, & Adela Langrock (1999) investigated sex differences in young children's spatial skill. The authors developed a spatial transformation task, which showed a substantial male advantage by age 4 years 6 months. The size of this advantage was no more robust for rotation items than for translation items. This finding contrasts with studies of older children and adults, which report that sex differences are largest on mental rotation tasks. Comparable performance of boys and girls on a vocabulary task indicated that the male advantage on the spatial task was not attributable to an overall intellectual advantage of boys in the sample.

Linn, Petersen, Linn, Marcia Petersen, & Anne (1985) described the Emergence and Characterization of Sex Differences in Spatial Ability: A Meta-Analysis. Child development, Sex differences in spatial ability are widely acknowledged, yet considerable dispute surrounds the magnitude, nature, and age of first occurrence of these differences. This article focuses on 3 questions about sex differences in spatial ability: (a) what is the magnitude of sex differences in spatial ability? (b) On which aspects of spatial ability are sex differences found? And (c) When, in the life span, is sex differences in spatial ability first detected? Implications for clarifying the linkage between sex differences in spatial ability and other differences between males and females are discussed. They use meta-analysis; a method for synthesizinge empirical studies, to investigate has questions. Results of the meta-analysis suggest (a) that sex differences arise on some types of spatial ability but not others, that large sex differences are found only on measures of mental rotation, (c) that smaller sex differences are found on measures of spatial perception, and (d) that, when sex differences are found, they can be detected across the life span.