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SPATIAL VISUALIZATION ABILITY: EFFECTS OF LONG TERM PRACTICE AND RELATIONSHIP TO MATHEMATICAL ABILITY

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SPATIAL VISUALIZATION ABILITY: EFFECTS OF LONG TERM PRACTICE AND RELATIONSHIP TO MATHEMATICAL ABILITY

by

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ABSTRACT

This investigation was designed to test a hypothesis formulated by Julia Sherman (1967) concerning the development of spatial visualization and mathematic skills. The intention of the study was to examine the influence of early physical training on spatial visualization and mathematic skills, to determine whether intensive training in spatial relations would have a differential impact on male/female spatial performance and to gather information concerning the relationship between spatial visualization and mathematic performance.

The investigation was divided into three studies and used 166 college students as subjects. Study one examined the impact of long term physical training, gymnastics, on spatial visualization and mathematic scores of two matched-groups selected from 99 subjects. The two groups, gymnast and control, each consisted of 28 subjects (14 males and 14 females) and were matched on IQ score, age, ethnic group, socioeconomic status, parental and sex-role identification, achievement motivation and years of training in other sports. Gymnasts averaged 5.5 years of gymnastic training; the control group had none. Study two examined spatial visualization scores obtained by 67 architectural students (49 males and 18 females) before and after a semester's training in spatial relations. Study three compared scores obtained by all 166 subjects on the Shepard Metzler Mental Rotation Test and a mathematic test derived from the Otis Test of Mental Abilities.

The test of the hypothesis relating to the influence of early physical training on spatial and mathematic performance was not successful as the training of the gymnasts did not extend to early childhood. While significant sex-related differences favoring males were found in spatial performance, the amount of variance in spatial scores accounted for by sex was small, only 8%. No significant sex-related differences in mathematic performance were found. In study two, both males and females significantly improved spatial performance following training, but females did not demonstrate a significantly greater rate of improvement as predicted. The results of the third study indicated a moderate positive relationship between spatial and mathematic performance, however, no evidence was found to support a direct causal relationship between spatial skill and mathematic performance.

CHAPTER 1

INTRODUCTION

The purpose of this study was to examine a hypothesis proposed by Julia Sherman in 1967 which was concerned with the acquisition of spatial visualization skills and the consistent findings of sex-related differences favoring males. Sherman, arguing essentially from a socialization viewpoint, suggested the findings of sex-related differences in spatial visualization performance were related more to sex-role differences, i.e., socialization practices, that exaggerated small innate differences or styles, than to a strong hereditary component. Sherman further suggested that findings of sex-related differences in mathematic problem solving performance were related to differences in spatial visualization skills.

Research in the area of sex-related differences confronts the investigator with a number of problems not usually foreseen in the initial undertaking of such a project. For example, the use of terms is confusing and sometimes subject to misinterpretation. Interpretation of the literature, especially that of cross-cultural studies, is a complex and difficult task. Methodology and statistical analysis present unique problems. Finally, the investigator must deal with controversial issues that at this time seem unresolvable. For these reasons it seems important to briefly review general issues and problems relevant to this research area before focusing on the specific interests and goals of this study.

Terminology

What is a sex difference? Does the construct have any practical meaning? The term sex difference has been used variously to describe some observed variation in human behavior on the basis of biological sex or on the basis of psycho-social sex or both. Most commonly it implies differences due to biological sex and that is the meaning that will be used in this discussion. The terms, gender-identity and gender-role identity often present difficulties as the first, gender-identity refers to the awareness and acceptance of biological sex i.e., male or female, while the second term, gender-role identity specifies the acceptance of the socially defined role and behaviors associated with being male or female (Frieze et al. 1978). To avoid confusion and to insure some measure of clarity the term sex-role difference will be used to indicate differences largely attributed to social or psychological causes and the term sex-related difference will be used as a neutral term to describe differences observed between male and female groups without implying either social or biological causation (Sherman 1978).

As to the second question, "does the construct have any practical meaning?" at least one person thinks not. Fairweather (1976) believes that the findings of sex differences in American studies are artifacts of techniques, culture or a combination of the two. Others disagree, citing evidence to support a small number of attributes and cognitive behaviors on which the sexes differ (Maccoby and Jacklin 1974). On another level, sex-role stereotypes are widely held and the impact on human thought, attitudes and behavior has been sufficent to impose limits on many individual lives. It is at this point that the construct of sex differences truly takes on practical meaning.

Cultural Universals

Distinguishing between sex differences (biological) and sex-role differences (sociocultural) is extremeiy difficult. A major area of controversy is whether certain differences presumed to be due to social practices, actually reflect basic human biological realities. Many researchers have used the concept of cultural universals as a guideline. If a behavioral difference is found consistently across varying cultures, then that difference is believed to have a biological basis. Cultural universals are not easily distinguished and the decision that a particular behavior represents a cultural universal is often a value judgment. Advocates of the socialization viewpoint commonly cite cultural exceptions as evidence against a biological argument. Proponents of the biological view rebut this argument stating that varying environmental factors could have resulted in diverging evolutional pathways that could have altered the relevant biological mechanism in some cultural groups (Frieze et al. 1978). Sherman (1978) raises another possible mechanism suggesting some differences between sexes may be the indirect result of ubiquitous differences in sex-role which were based on biological differences that are no longer effective factors.

Methodology

The quality of research in this area has been poor for a variety of reasons. Historically research was biased, due in large part to nonconscious ideologies society held about females. Early psychologists did not collect data on females because females were not considered important, male data was held to be normative. This view was also reflected in the fact that very few females were present in the universities, either as students or faculty, where most of the research was carried out. As a result psychological research used males only as experimenters or subjects. This bias persisted in many ways in later research, for example, the use of male-biased tasks in experiments and the view that behavior was dichotomous rather than integrated, particularly in regard to conceptualizing masculinity and femininity (Frieze et al. 1978).

Many of the early reports of sex differences came from studies that were actually investigating other aspects of behavior but which had included sex and age as variables and reported significant differences found by sex or age as a matter of routine. Since sex and age cannot be randomly assigned as subject variables, their use as independent variables does not justify conclusions that variation in behavior has been caused by them (Wittig 1979). In many other instances, methods were poor and statistical analyses were largely inadequate. Some studies erroneously extrapolated differences from single sex studies, while others mistakenly interpreted different patterns of findings within each sex as sex differences. For example, Maccoby cited a case in which Sears, Rau and Alpert (1965) found verbal aggression to be more frequent than physical aggression in a sample of preschool girls. The reverse was true in the sample of preschool boys. Maccoby noted, "Although there was no ambiguity about the presentation of the original findings, they were later interpreted as showing that girls were higher than boys in verbal aggression. In fact, boys showed more of both kinds of aggression than girls showed." (Maccoby and Jacklin 1974; p. 7). Another source of misinformation has been the practice of accepting only those studies with findings of significant results for publication. In this area, the finding of no significant results may be as important. A continuing problem has been the method of reporting statistics. Differences between sexes have been found in only a small number of characteristics and there is usually a large amount of overlap in scores. However, differences are generally reported in terms of mean scores and give no sense of the practical significance of the difference. There is a need for more meaningful statistical indices, i.e., strength of association or overlap measures. Few studies report these statistics or provide sufficient data for calculating them (Maccoby and Jacklin 1974; Petersen and Wittig 1979; Sherman 1978).

Nature-Nurture

Because research in this area involves consideration of both genetic and environmental variables, the issue of nature-nurture is inevitably raised. Although this issue has seemingly been laid to rest as being over simplistic and inappropriate (Anastasi 1965; Dobzhansky 1968; McClearn and DeFries 1973), there is a tendency for this issue to be reflected in the literature of sex-related differences. Current scientific opinion holds that human development is the result of the complex interaction between both genetic and environmental factors. Using this approach, the appropriate questions to be asked are, "How important is the contribution of each factor and what is the mechanism of the interaction (Frieze et al. 1978).

Sexual Differentiation

A person is not just simply born male or female. Many factors are important in the differentiation of sex; both prenatal and postnatal events play an important role. Sexual differentiation involves complex interactions between physical and psychological factors that are not yet clearly understood. Further, biological differences between the sexes obviously may play an important part in the development of psychological characteristics (Mischel 1965).

Males and females are usually easily distinguished from one another at birth by a simple inspection of the external genitalia. There are more biologic criteria for differentiating males from females including sex chromosomes, sex hormones and reproductive organs. Levitan and Montagu (1977) list three genetic and six post genetic characteristics useful in the identification of sex.

1. Genetic constitution (genetic sex)
2. Chromosomal constitution (chromosomal sex)
3. Nuclear constitution (nuclear sex)
4. Gonadal structure (gonadal sex)
5. Hormonal status (endocrinologic sex)
6. Morphology of external genitalia (external genital sex)
7. Internal ductal differentiation (internal genital sex)
8. Sex of rearing (social sex)
9. Gender role (psychologic sex)

Genetic constitution with reference to sex is generally identified with the chromosomal sex complement, XX=female, XY=male. Although such an identification successfully identifies sex in most cases, it fails in others. It is not the chromosomes but the genetic material in them that directs development in the male or female direction. For example, 46 XX individuals may exhibit a male phenotype and some 46 XY individuals appear to be females (Levitan and Montagu 1977). The study of such individuals has provided useful information regarding the role both biology and social factors play in the determination of sex identity and sex-role behavior and will be discussed later in the text.

Alfred Jost (1972) is credited with the first explanation of the fundamental mechanisms of sexual differentiation as a sequential, ordered and relatively simple process. Chromosomal sex determined at conception directs the formation of either ovaries or testes. If testes develop, their hormonal secretions, androgens, direct the development of male secondary sex characteristics but if an ovary develops, or if no gonads are present the development is female (Wilson, George and Griffin 1981).

Male Development

The primordal genital tract of both sexes has three components, undifferentiated gonadal tissue, two genital duct systems (Wolffian and Mullerian) and a common opening for the genital ducts and the urinary tract to the outside through the genital folds on the abdominal wall. In the development of a male the burden of sex differentiation depends upon the testes as they and their masculinizing hormone must be formed early in development. During the sixth week of embryonic life a message is sent that directs the development of testes in the XY embryo. Although not conclusively demonstrated, H-Y antigen has been implicated as a director of gonadal differentiation as the appearance of this antigen has been strongly correlated with the presence of the Y chromosome. Once the testes form, they begin to secrete testosterone and the Mullerian ducts begin to regress and eventually disappear. Mullerian duct regression is quickly followed by virilization of the Wolffian ducts and anatomical development of male internal and external genitalia is completed largely by the end of the first trimester (Avers 1974; Haseltine and Ohno 1981; Wilson et al. 1981).

Female Development

If the chromosomal complement possessed by the embryo is female (XX) differentiation of the primordal gonadal tissue does not begin until the twelfth week. At that time the tissue differentiates into ovaries which begin to produce the hormone, estrogen. Unlike androgens, estrogens produced by the ovaries do not appear to have a major role in the early characteristics of sex differentiation but do appear to play a role in oocyte development and the completion of meiosis. The Wolffian duct system regresses and the Mullerian duct system develops into the fallopian tubes and uterus and contributes to the development of the vagina. The external genitalia undergo little differentiation compared with the undifferentiated state (Avers 1974; Haseltine and Ohno 1981; Wilson et al. 1981).

Physical Differences

Males and females differ quite clearly on a large number of physical variables including body build, anatomical characteristics, physiological functioning and biochemical composition. Many of these attributes are apparent at birth and increase with age. Males are approximately 5% heavier than females at birth and weigh about 20% more than females at age 20. On the average, males exceed females in height by 1% to 2% throughout childhood and exceed females by approximately 10% by age 20. Females have less muscular strength at all ages as they have proportionately less muscle and more body fat than males from birth on. Males also have a greater vital capacity (total volume of air expelled from lungs after maximal inhalation) than females at all ages. In early childhood the average vital capacity of males is approximately 7% higher than that of females and by adulthood the male exceeds the female in vital capacity by approximately 35%. This difference is especially significant because vital capacity is an important factor in sustained energy output (Anastasi 1965). One of the most pronounced physical differences is the rate of physical maturation, this difference begins before birth as the ossification of the skeletal system proceeds more rapidly in females than in males. In females the bones begin to ossify one to two months before the same bones ossify in males and the process is finished one to two months earlier. This process of skeletal maturity in females accelerates over the lifespan so that by age five a female is one year ahead of the male and at age thirteen she is two years ahead. Because of this difference in maturational rate, females are larger than most males in nearly all respects during the age span of 10 1/2 to 13, after which the effects of the males later growth spurt becomes noticeable. Females stop growing earlier than males reaching 98% of their final height by age 16 1/2, while males stop growing at about 17 3/4 years (Tanner 1973). Other differences are related to reproductive functioning, females menstruate, gestate and lactate, males do not. Males produce sperm in the hundreds of millions daily while females typically produce only one ovum per month (Avers 1974). While these physical differences are responsible in some way for eliciting behavioral differences between males and females, their influence is not readily apparent in other dimensions of human behavior. Very few differences are found between the sexes in psychological or cognitive functioning and the amount of variance accounted for by sex is generally small. It is most often the case that cognitive differences found between individuals of the same sex are as great or greater than differences found between individuals of the opposite sex (Avers 1979; Petersen and Wittig 1979).

Influence of the Socialization Process

The process of socialization has a powerful influence on male-female behaviors in most cultures. Sex-role stereotypes, gender identity and sex-typing of traits, cognitive abilities and activities are important factors that contribute to sex-related differences in behavior. The significance of the socialization process has been demonstrated by the work of John Money and his associates in a series of studies involving androgenized genetic females, androgen insensitive (XY) females and sex reassignment due to misdiagnosis at birth or injury. In the case of sex reassignment, results indicated that development of normal sex-role behavior is a process that is acquired by age three or four. Reassignment of sex after this age was judged to cause severe maladjustment, whereas reassignment of sex prior to this age produced children with normal sexual adjustment. In 1965, Money concluded:

> These studies led the clinical investigators to the conclusion that the establishment of gender role or psychologic sex can be independent of chromosomal sex, gonadal sex, hormonal sex, internal reproductive structures and external genital morphology... Psycho-social differentiation is an active process that takes place after birth and needs the stimulus of interaction with a behavioral environment, in much the same manner as does acquisition of a language. In certain indicative cases, the sex of assignment can override the influences of the physical variables of sex. (Money 1965).

Money's conclusions were later challenged. Imperato-McGinley et al. (1974) reported pubertal shifts from female to male gender identity in a group of pseudohermaphrodites in a rural area of the Dominican Republic. At birth these individuals appeared to be female, although there were profound ambiguities of the genitalia. Thirty-three living subjects were identified, nineteen of these subjects were reported to have been raised unambiguously as females and information was obtained on eighteen of the subjects. Out of the eighteen subjects raised as females, seventeen were reported to have successfully changed to a male gender and of the seventeen, sixteen to a male gender-role. Imperato-McGinley et al. concluded that testosterone exposure during the prenatal, perinatal and pubertal stages of development was the most significant factor in the normal differentiation of male gender identity. This conclusion was in direct opposition to Money's view that sex of rearing is the single most important factor in sex-identity or gender-identity, and has caused considerable controversy. Rubin, Reinisch and Haskett (1981) suggested that it was not clear whether the Dominican subjects were raised unambiguously as females and that they may have experienced gender-identity confusion during childhood sufficient to allow a transition at puberty. In support of this view, they cited a case in the United States in which eight individuals with the same genetic defect were raised as females and who apparently maintained their gender identity despite disfiguring pubertal virilization.

Development of Sex-Roles

Kohlberg (1966) formulated a model that incorporated the concept of gender identity or self categorization as the basic organizer of sex-role behaviors and attitudes. He proposed the following process of self-socialization. Gender-identity results from a basic physical reality judgment of sex made early in the child's development. The concept that gender-identity is constant and enduring takes some time to develop. During this period (approximately age 2-7 years) the child's sex-role concepts are significantly influenced by environmental factors. Once the child has categorized personal sex, the child begins to value that categorization and begins to value others of the same sex. Sex-role stereotypes are acquired, that are at first rigid, oversimplified and exaggerated. However, since these stereotypes cause the child to develop masculine or feminine values, the child tends to identify with like-sex persons especially the appropriate parent. As the child matures, sex-role concepts are expanded and become more flexible.

Because there is disparity between Kolhberg's model relating to the age of acquisition of gender constancy and Money's findings that sex reassignment could only be successfully accomplished up to age four, Maccoby and Jacklin (1974) suggested the concept of gender constancy was not necessary for the process of self socialization into sex-roles to begin. They speculated that children as early as age three begin to grasp the concepts of their own gender-identity even though their ability to group others by sex is imperfect. While a boy may not be certain of the permanence of that status, as soon as he knows he is a boy in any sense, he is likely to begin to prefer to do boy-like things. Although processes of direct and indirect reinforcement and imitation are involved, the most important factor is the child's realization of his or her own sex.

Cognitive Differences

In their comprehensive review of the literature of sex-related differences Maccoby and Jacklin (1974) concluded there were four areas in which sex-related differences were fairly well established. Those areas included verbal ability, visual-spatial ability, mathematic ability and aggression. In order to meaningfully examine differences found in their survey of a large number of studies using a variety of scales, Maccoby and Jacklin calculated differences in standard score units as the measure of magnitude of difference. Since this investigation was concerned solely with cognitive functioning, specifically visual-spatial and mathematic, the topic of aggression will not be addressed and the topic of verbal ability will be discussed only as it relates to the Sherman Hypothesis.

Verbal Ability

Maccoby and Jacklin (1974) concluded that there was evidence of female superiority in verbal abilities. Female verbal abilities appeared to mature more rapidly, although there were many studies in which no sex-related differences were found. Males and females are believed to have similar abilities from preschool through early adolescence. At age 11, the sexes begin to diverge with female superiority increasing through high school and possibly beyond. Females scored higher on tasks involving both receptive and expressive language and in high level verbal tasks (analogies, comprehension of difficult material and creative writing) as well as on lower level tasks (fluency). The magnitude of female advantage was calculated to be approximately .25 of a standard deviation.

Mathematic Ability

The two sexes were found to be similar in the early acquisition of quantitative concepts and mastery of arithmetic during grade school. At age 12 or 13 males' mathematic skills increased faster than did females'. According to Maccoby and Jacklin the greater rate of male improvement did not appear to be a function of the number of mathematic courses taken. However, they did note that this question had not been extensively studied. Later research has demonstrated that a disparity between sexes in the number of mathematic courses taken has a relationship to findings of sex-related differences in mathematics (Fennema and Sherman 1977). The magnitude of difference was reported to vary over populations. No figure was given but it was stated that it was believed to be smaller than the magnitude of difference in spatial ability.

Visual-Spatial Ability

Maccoby and Jacklin (1974) reported that male superiority on visual-spatial tasks was fairly consistently found in adolescence and in adulthood but was not found during childhood. The male advantage on spatial tasks increased through high school years to a magnitude of difference of approximately .40 of a standard deviation. In the studies surveyed the difference was reported to be approximately equal on both analytic and non-analytic spatial measures. Maccoby and Jacklin questioned findings on analytic measures and suggested that there are equivocal findings when pure analytic measures are administered.

CHAPTER 2

SPATIAL ABILITY

The process of perceptual learning and the development and acquisition of perceptual skills has not been extensively investigated. As a result, the process of perceptual learning is poorly understood and has not yet been well formulated (Santos and Murphy 1960). Indeed, as will be acknowledged later in the discussion spatial factors have not yet been satisfactorily categorized or defined. Researchers from many areas of psychology have investigated various aspects of perceptual learning (see Gibson 1953 for a review). However, the approaches apparently have been sufficiently different to prevent a major integration of findings.

The space factor was one of the first factors isolated by Thurstone in his factor analytic studies of primary mental abilities and the second most frequently isolated factor up to 1940 (Barratt 1953; Thurstone 1938, 1941). Although Thurstone's studies generated a tremendous amount of interest and research in the investigation of separate abilities, developmentalists favored another approach. Developmental research focused largely on developing theories concerning the acquisition of information processing strategies and there was little interest in the investigation of development and acquisition of separate abilities. Separate abilities were investigated only in terms of whether these abilities became more or less differentiated during intellectual development. The common assumption was that such abilities emerged as distinct factors in early and middle childhood, then blended with other factors at maturity. If a factor remained distinct, it was believed to represent a lower level of intelligence. Evidence from a variety of studies indicates that this assumption was not correct, particularly in terms of spatial ability (Maccoby and Jacklin 1974). Spatial ability appears to become increasingly distinct with age (Sherman 1967; Vandenberg and Kuse 1978, 1979; Witkin et al. 1954) and has been implicated as being a major component of both mechanical skills and higher level cognitive processes (Fennema and Sherman 1977; Sherman 1967; Werdelin 1961).

Definition of Space Factors

Sherman (1978) defines spatial cognition as the knowledge and internal cognitive representation of the structures, entities and relations in space. Spatial ability can be broadly defined as the practical ability to manipulate, and use these mental representations of, and relations in, space. Spatial perception can refer to several modalities, audio-spatial perception, tactual-perception or visual-spatial perception. Visual-spatial perception has been the most frequently studied component of spatial perception. While the broad definitions of spatial cognition and ability are generally acceptable, there is much confusion about the labels and number of spatial abilities. When the space factor was first isolated, it was believed to be a unitary trait. Although there is general agreement that there is more than one factor, there is no agreement as to either the number of space factors or their definitions.

French (1951) suggested two space factors, spatial orientation and spatial visualization. He defined spatial orientation as the ability to remain unconfused by the changing orientations in which a spatial configuration may be presented. Spatial visualization was described as the ability to comprehend imaginary movements of objects in three-dimensional space. Guilford and Zimmerman (1948) used the same terminology in proposing two factors, but defined them somewhat differently. Spatial orientation became the ability to appreciate spatial relations with reference to the body of the observer, while spatial visualization was defined as the ability to imagine movements, transformations and other changes in visual objects. Sherman (1978) describes four space factors and some tests typically used to investigate these factors:

1. Spatial Relations and orientation--The ability to comprehend the arrangement within a visual stimulus pattern using one's body as the frame of reference. Tests--Flags, Cards.
2. Spatial Visualization--The ability to mentally manipulate an object or parts of a configuration. Tests--Space Relations Test.
3. Right-left discrimination--no tests given.

4. Gestalt Flexibility--This factor involves the ability to retain a configuration so as to pick it out in spite of organized perceptual distractions. This factor has also been termed Field Independence-Dependence or Cognitive Analytic Style versus Global Style. Tests include the Embedded Figures Test (EFT) and the Rod and Frame Test (RFT).

Horn (Vandenberg and Kuse 1979) noted the high intercorrelations of tests of spatial ability and concluded that there was a general spatial visualization factor composed of at least seven mental abilities. These factors, identified through factor analysis, included Figural Relations, Visualization, Spatial Orientation, Flexibility of Closure, Speed of Closure, Perceptual Speed and Figural Adaptive Ability.

> The seven primary abilities are defined by tasks requiring subjects to imagine movements in space, to find configurations embedded within other configurations, to bring about closure among parts of a configuration, or to quickly scan several configurations and locate a particular one. Tests designed to measure one of these primary abilities almost certainly measure two or more to a varying degree (Vandenberg and Kuse 1979).

Spatial Visualization

Shepard and Metzler (1974, 1971) extensively investigated the spatial visualization factor and produced a relatively pure measure in that it apparently excludes verbal mediation as a problem solving strategy. The researchers began a series of experiments in 1969 designed to measure the time human subjects required to respond discriminantly to spatially transformed objects.

Shepard and Metzler hypothesized that the solution process involved an internal mental process that corresponded on a one-to-one relationship to an actual physical process of rotation of an object. They termed this cognitive process Mental Rotation. During the experiments the subjects were presented with a pair of perspective drawings of three dimensional objects that differed in portrayal of angular or picture plane (depth) rotation. The subjects were instructed to determine as rapidly as possible whether the two drawings had the same shape. Shepard and Metzler found an almost perfect correlation between the amount of rotation, angular or picture plane, and the amount of time taken for a decision. They concluded that these findings were best explained by the process of internal mental rotation and the subjects also explained their decision process in terms of a mental rotation (Shepard and Metzler 1974, 1971; Cooper 1976).

A Three Dimensional Test of Spatial Visualization

Vandenberg and Kuse (1978) developed a paper-and-pencil test from the original drawings used by Shepard and Metzler. The Mental Rotations test contains twenty items in five sets of four items. Each item consists of a criterion figure, two correct choices and two distractor choices. Correct choices are identical to the criterion figure but are shown in a rotated position (some multiple of 20°). Half the distractor choices are rotated mirror images of the criterion figure and the other half are rotated images of other criterion figures. Vandenberg and his associates have administered this test to large population samples and have obtained substantial internal consistency (Kuder-Richardson 20 = .88), and Test-Retest reliability (.83)(Wilson et al. 1975; Kuse 1977).

The Mental Rotation Test correlated strongly with other tests of spatial ability but showed low correlations with tests of verbal ability (Vandenberg and Kuse 1979; see Table 1 below). Wilson et al. (1975) obtained pronounced sex-related differences in an ethnically diverse group of 2,498 individuals tested in Hawaii. (see Figure 1).

Table 1. Correlations Between Spatial and Verbal Tests (N = 172).

TESTS	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Mental Rotations	46	24	29	34	22	35	30	19	05	08	00	03	07
2 Object Aperture		21	33	34	33	38	03	25	-01	-04	12	07	17
3 Cube Comparisons			39	37	29	27	28	21	18	13	18	03	10
4 DAT Spatial Relations				44	34	34	27	16	12	10	06	02	03
5 Card Rotations					38	36	24	10	02	00	08	06	04
6 Flags						19	09	21	20	21	16	17	02
7 Copying							35	22	21	19	14	10	05
8 Hidden Patterns								21	35	33	17	09	16
9 Hidden Figures									27	36	33	21	15
10 Paper Form Board										60	26	10	21
11 Folded Squares											18	12	-04
12 Vocabulary												30	14
13 Word Endings													25
14 Verbal Reasoning													

From Vandenberg and Kuse 1978.

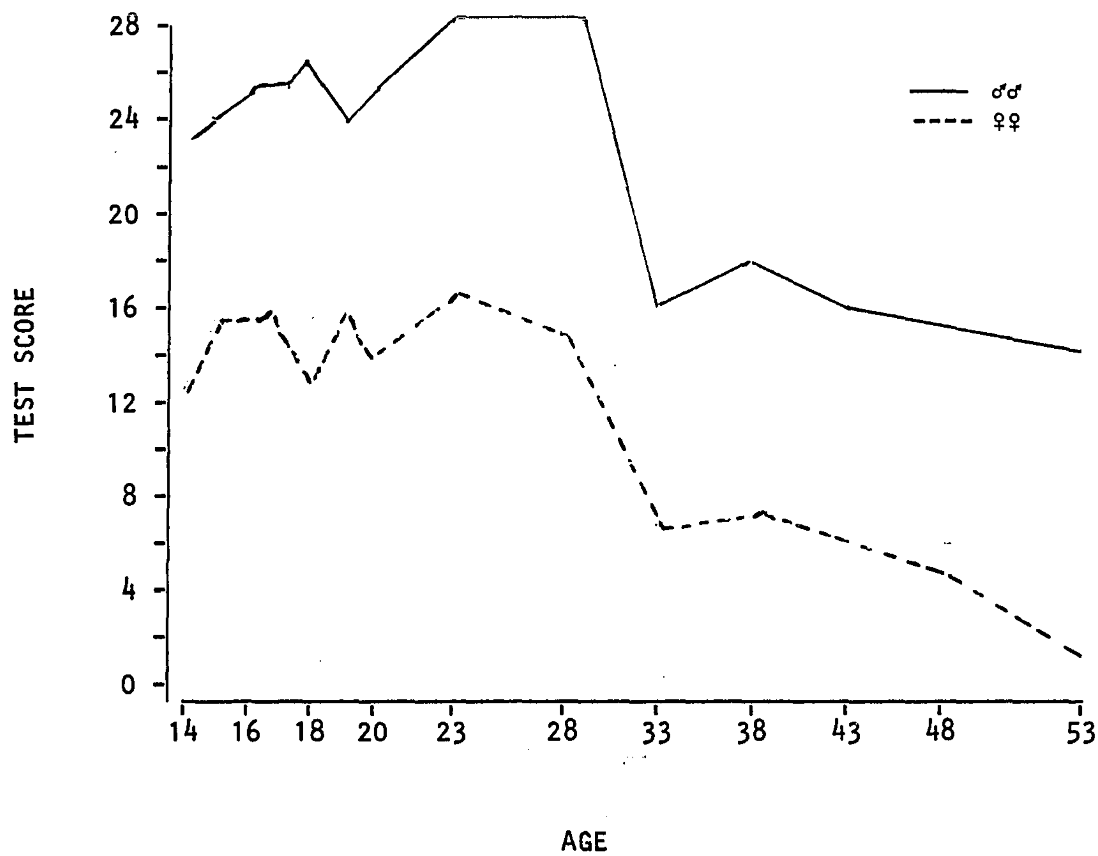

Figure 1. Male and Female Age Curves for the Mental Rotations Test (after Wilson et al. 1975). Taken from Vandenberg and Kuse 1978.

Sex-Related Differences, Spatial Ability

Sex-related differences in tests of spatial abilities have been consistently reported over the years. Males were found to be superior to females in spatial ability and this difference was reported to emerge as early as age six (Anastasi 1965; Maccoby 1966; Sherman 1967). Maccoby and Jacklin (1974) believe that many of these findings can be directly related to the single factor of visualization. They distinguish two components of spatial visualization, nonanalytic and analytic. Nonanalytic spatial visualization involves the ability to visually rotate an object or figure without the aid of verbal mediation (Petersen and Wittig 1979) while analytic spatial visualization refers to the ability to distinguish elements of a complex situation by disregarding the general context. The analytic person is able to perceive an item as separate from its background and to break, set or restructure the situation (Maccoby and Jacklin 1974). A good example of the confusion generated in analytic studies has been the frequent use of the Embedded Figures Test, the Rod and Frame test and the Block Design Subtest from the Wechsler Scales as measuring instruments. These tests were believed to specifically tap analytic spatial visualization skills. Females generally have scored poorly on these tests in contrast to males (Maccoby and Jacklin 1974; Witkin et al. 1954). Findings of poor female performance on these measures have been uniformly interpreted as evidence of inferior female spatial ability and also as evidence of a different cognitive style. Females have commonly been described as accepting the field more passively than males and being more field dependent or global as opposed to being field independent and analytical in their cognitive style (Sherman 1967). However, it has been demonstrated that these tests also contain a strong nonanalytic spatial visualization component. When this component is controlled or removed on these tests, sex-related differences disappear (Hyde, Geirenger and Yen 1975; Yen 1975). No reliable sex-related differences have been found on analytic tests designed to eliminate the nonanalytic spatial visualization component (Maccoby and Jacklin 1974).

Investigations of the spatial visualization factor have been devoted largely to the documentation and examination of sex-related differences as having a possible genetic basis (i.e., Bock and Kolakowski 1973; Bourchard and McGee 1977; DeFries et al. 1979; Hartlage 1970; Stafford 1961), or to an examination of the relationship of spatial sex-related differences and mathematic achievement (Fennema and Sherman 1977; Hyde, et al. 1975; Maccoby 1966, 1974), and personality variables (Barratt 1953; Gruen 1955), and perceptual experience or training (Gill, Herdtner and Lough 1968; Goldstein and Chance 1965; Gruen 1955; McGee 1978b). Lately, investigators have examined differences in patterns of hemispheric engagement (Ornstein et al. 1980) and in problem solving strategies (Allen 1974; Allen and Hogeland 1978; McGee 1978a) in different spatial visualization tasks.

The nonanalytic spatial visualization component is believed to emerge at adolescence as it is at this point that males begin to demonstrate superior spatial performance (Fruchter 1954;

Maccoby 1966; Witkin et al. 1954). The apparent parallel emergence of sex-related differences in higher level mathematics has suggested a relationship between the two abilities to many researchers.

<u>Relationship to Mathematics</u>

Although the relationship of visual-spatial ability and higher order mathematics seems logical, the data are conflicting. Many factor analytic studies have investigated this relationship. Some researchers have concluded that spatial ability and mathematical ability are not related (Fruchter 1954; Smith 1964; Very 1967). Werdelin (1961) stated that while he was not able to definitely conclude that the empirical data indicated a relationship between spatial ability and geometry, there was strong pedagogical reason to believe in a connection between the ability to visualize and geometric ability. Other researchers believe that the accumulated evidence indicates a positive relationship (Guilford, Green and Christiansen 1951; French 1951, 1955). In a review of the literature, Aiken (1973) stated that spatial perceptual ability was one of the most salient factors extracted in various investigations.

Recent research findings have not resolved the relationship and the debate continues. Hyde et al. (1975) found sex-related differences in both spatial performance and in mental arithmetic in a group of first year college students. They were able to eliminate significant sex-related differences in mental arithmetic by removing differences in spatial ability, although non-significant mean differences in favor of males remained. Fennema and Sherman (1977) found only small sex-related differences in spatial performance in two of four high school populations and only one population in which sex-related differences in spatial performance coincided with sex-related differences in mathematic achievement. By co-varying the difference in spatial performance, they also were able to eliminate the difference between sexes in mathematic achievement. While still maintaining the relationship between spatial skills and mathematic skills, the authors noted, "The patterns of differences in mathematic achievement, spatial visualization, and affective variables strongly suggests the influence of sociocultural factors." Other researchers have suggested that sociocultural factors may be more important in producing sex-related differences in mathematics, i.e., attributing differences to culturally influenced attitudes that mathematic interest or ability are not appropriate for females (Dwyer 1974; Kagan 1964; Paulsen and Johnson 1983), or to a conditioned mathematic avoidance response more common in females (Tobias 1978).

In 1980, Benbow and Stanley found large sex-related differences in mathematical reasoning ability in their study of intellectually gifted junior high school students. In spite of the fact that no measures of spatial ability were administered, and though their data supported the hypothesis that these differences were somewhat increased by environmental factors, Benbow and Stanley favored the hypothesis that superior male achievement in and attitude towards mathematics was related to greater male ability in spatial tasks. This appears to be a common reaction in this area and most researchers appear to agree with the hypothesis relating spatial visualization skill and mathematic skill. However, as Fennema (1975) pointed out, there is still little in the way of empirical data to confirm or disconfirm this hypothesis. There is a strong need for information in at least two areas, more correlational studies relating the two abilities and information on the effects of differential spatial visualization ability on the mathematics learning of males and females.

Origin of Sex-Related Differences

Many hypotheses have been formulated to account for findings of sex-related differences in spatial skills. Three hypotheses reflect the biological viewpoint, the sex-linked recessive gene hypothesis, the hormonal hypothesis, and the brain lateralization hypothesis. A major proponent of the socialization viewpoint, Sherman (1967, 1971, 1978) proposed a process whereby small innate differences are exaggerated by differential socialization practices that provide more relevant training and experience in spatial visualization skills for males than females throughout development.

Biological Approach

X-Linked Recessive Gene

Research in twin studies has provided evidence that spatial abilities have a significant genetic component and that they may also be less prone to environmental influence than other cognitive abilities such as verbal ability (Vandenberg 1968). O'Conner (1943) was the first to suggest the possibility of a sex-linked recessive gene for spatial ability, based on his observations of differential spatial performances by males and females.

Certain traits, termed qualitative, are believed to be controlled by single major genes (e.g., hemophilia, color blindness). A gene at any given locus on a chromosome may possess several variant forms called alleles. In the simplest case of two alleles (A and a), expressed in a nonadditive fashion, a person who inherits a pair of alleles that are different from each other (Aa rather than AA or aa) will phenotypically express the effects of one allele and not the other. The expressed allele (A) is said to be dominant over the other allele (a) which is called recessive. In autosomal inheritance, only those individuals possessing both recessive alleles (aa) will express the recessive trait. Transmission of a recessive trait determined by sex-linked alleles (located on the X chromosome and better termed X-linked) follows a specific pattern based on the distribution of the X chromosomes from parents to progeny. The characteristic feature of recessive X-linked inheritance is the lack of father to son transmission, based on the fact that a male receives an X chromosome only from his mother. The female, however, receives two X chromosomes, one paternal and one maternal. In females, the inheritance of X-linked genes is the same as autosomal inheritance as they inherit both alleles while males inherit only one or the other of two possible alleles (Wittig 1979). Therefore, the particular trait that is phenotypically expressed in males depends on the X-linked allele inherited from the mother. Phenotypic expression of X-linked alleles in females is somewhat complicated. Although females inherit two X chromosomes which are present in all cells (both somatic and gonadal), there is evidence that the genetic material in only one of the two X chromosomes actively functions or is expressed in the somatic cells. Lyon (1961) has proposed that during early fetal stages one of the two X chromosomes is inactivated on a random basis. Phenotypic expression of an X-linked recessive allele in a heterozygous female (Aa) then could vary according to the ratio of active to inactive (A:a) somatic cells. If a gene has two alleles, the frequency of expression for an X-linked recessive allele in males would equal the frequency of the X-linked allele in the population. Since females inherit two chromosomes, the frequency of expression of the recessive allele in females would be expected to be the square of the frequency of the recessive allele. For example, if the population frequency of a recessive allele is equal to (.5) then fifty percent of males would be expected to express the trait while only twenty-five percent of females $(.5)^2$ would be expected to express the trait (Bock and Kolakowski 1973). This pattern of inheritance also produces a characteristic pattern of familial correlations, i.e., the father-daughter correlation is approximately equal to that of the mother-son correlation, the mother-son correlation exceeds that of the mother-daughter correlation and the father-son correlation is near zero or (Father-daughter ≅ Mother-son) > (Mother-daughter) > (Father-son ≅ 0). Evidence for the sex-linked hypothesis is confusing and indicative of the need for further research in this area. A small group of studies (Bock and Kolakowski 1973; Hartlage 1970; Stafford 1961) demonstrated parent-child correlations that supported the sex-linked hypothesis. These studies were criticized as being inadequate in both subject numbers and number (one) of spatial tests used. Yen (1975) administered four spatial tests to 2,508 high school students and found sibling correlations in the order predicted by a hypothesis of sex-linked inheritance. However, DeFries et al. (1979) found no evidence to support the sex-linked hypothesis in a large-scale family study (1,816 intact nuclear families, 6,581 individuals) using five test measures of spatial ability.

Hormonal Hypothesis

The possibility that spatial ability is androgen-limited is the basis of the hormonal hypothesis. This hypothesis was first suggested when it was discovered that individuals having Turners Syndrome (XO) performed poorly on spatial tasks (Bock and Kolakowski 1973). Turner's Syndrome (XO) females resemble males (XY) in that they have only one X and like males would be expected to express the recessive gene for spatial ability more often. However, their performance on spatial tasks was much poorer than males or females (Harris 1978; Friese et al. 1978; Maccoby and Jacklin 1974; Wittig 1979). The idea that spatial ability might be androgen-limited was further strengthened by the finding that androgen-insensitive females (XY) also demonstrated a pattern of low spatial skills (Bock and Kolakowski 1973; Money 1964, 1968). Both Turner's Syndrome (XO) and androgen-insensitive females (XY) have no functional androgen. Therefore, if high spatial skills were dependent on both the presence of a recessive gene and androgens, this could explain the pattern of low spatial skills in these two groups as well as the increase in spatial skills of males at puberty.

Brain Lateralization

The third hypothesis is based on the findings of a pattern of differential skills in the sexes (Females, high verbal skill and low spatial skill; Males, low verbal skill and high spatial skill) which appear to parallel the functions of the cerebral hemispheres. Based on a growing body of evidence that linguistic skills are localised in the left hemisphere and spatial skills in the right hemisphere, some researchers have speculated that the timing of lateralization may be important in the development of verbal and spatial skills. If the process of lateralization proceeded at a different rate in the two sexes, this difference might account for differences in the pattern of skills. Several researchers believe they have demonstrated that lateralization begins earlier in females than males (Kimura 1963; Knox and Kimura 1970) although this is strongly disputed by others (Fairweather 1976) and remains a controversial issue.

Buffery and Gray (1972) suggested that spatial skills require more integration between the two hemispheres (less lateralization) while verbal skills are improved by earlier stronger lateralization and left cerebral hemisphere dominance. Levy-Agresti and

Sperry (1968) have proposed an entirely different model, suggesting that early strong cerebral dominance enhances the development of spatial ability and that bilateral mediation of language interfers with the development of spatial skills.

Both these models rely on two assumptions, neither of which have been confirmed, one, that the sexes differ in degree of lateralization and two, that bilaterality for one skill affects the expression of the other. Maccoby and Jacklin (1974) raised an important point in their summary of this research area. They concluded that the constellation of skills localised in each hemisphere does not correspond to known sex-related differences in abilities.

> The left hemisphere is typically described as verbal, sequentially detailed, analytic and computer like. Although females are believed superior in a variety of verbal tasks, the rest of the description does not fit them better than males. A theory which purports to account for female superiority on verbal tasks and inferiority on spatial tasks in terms of stronger or earlier lateralization of the left hemisphere would have to predict that the other functions or skills controlled by this hemisphere would also be superior in females (Maccoby and Jacklin 1974; pp. 126-127).

Socialization Approach

Sherman Hypothesis

In 1967, Julia Sherman published a paper severely questioning the construct of an analytical cognitive style. Sherman argued that the key measures of this approach were substantially related to space perception, specifically to nonanalytic spatial visualization ability, and were therefore, sex biased. Accordingly, conclusions of sex-related differences in analytic ability based on such date would be unwarranted. Sherman concluded that the construct of an analytic style was very likely invalid. Sherman also advanced an argument that sex-related differences in spatial perception had been neglected as an explanation of sex-related differences in mathematical problem solving ability. In addition, Sherman proposed that superior male spatial skills were a reflection of early childhood differences between the sexes in verbal skills and exploratory behaviors which were further exaggerated by cultural sex-typing of activities. In essence, Sherman's "Bent Twig Hypothesis" stated that young females develop verbal skills earlier which tend to mediate a greater dependence on verbal, social interactions. Young males are unable to communicate as effectively and may use superior musculature to fill their needs. These early differences set the stage for sex differentials in the exploration of the environment and problem solving by action rather than by words. This trend is further extended and supported by a process of differential socialization. Young males are allowed more freedom to explore their environment and are encouraged to participate in games and activities and to play with toys that are less likely to exercise and develop spatial skills (Sherman 1967, 1971, 1978).

Hierarchical Learning Process

The concept of a hierarchical learning process is held by many developmentalists who believe that the acquisition of higher order abstract reasoning is dependent on a sequential process of action, internalization and abstraction (Piaget and Inhelder 1967).

> Developmental psychologists patterned on Piaget have theorized that at different stages of cognitive development certain modes of thought predominate and ideas are added to one's cognitive structure by utilizing actions, symbols which represent those actions, and symbols alone in somwhat different blends. According to this theory, mental structures are formed by a continual process of accommodation to and assimilation of the environment. This adaptation (accommodation and assimilation) is possible because of the actions performed by the individual upon his or her environment. These actions change in character and progress from overt, sensory actions done almost completely outside the individual; to partially internalized actions which can be done with symbols representing previous actions; to complete abstract thought done entirely with symbols. Thus, development in cognitive growth progresses from the use of physical actions to form schemas to the use of symbols to form schemas, i.e., learners change from a predominant reliance upon physical actions to a predominant reliance upon symbols. (Fennema 1975; p, 38).

Cross-Cultural Research

Investigations of cognitive components have demonstrated a wide range of variability across cultures. This evidence, as previously noted, is held to be consistent with the concept that assignment of specific sex-roles and differential socialization of the two sexes contributes strongly to observed sex-related differences where they are found.

Parlee and Rajagopol (1974) compared sex-related differences on the Embedded Figures Test among college students in India and the United States. While they found that men in each culture scored significantly better than women in that culture on the tests in both groups, they also found that Indian women scored higher that U.S. males. However, this difference did not reach a significant level. Berry (1966) found evidence for ranking cultural groups according to the level of field independence-dependence based on the level of acculturation to Westernized technology. In the United States, Ramirez, Castaneda and Herald (1974b) demonstrated this effect in Mexican-American children, the least acculturated children were significantly more field dependent. In a second study Ramirez and Price-Williams (1974a) found that both Mexican-American and Black children were significantly more field dependent than Anglo children. Witkin and Berry (1975) surveyed the cross-cultural literature and concluded that significant sex-related differences (in field independence-dependence) occurred with less frequency in cross-cultural studies than in Western studies. Culture appeared to be the overriding factor; agricultural societies elicited more field dependent scores while migratory hunting societies produced the more independent scores.

Effects of Training

Research findings from studies investigating the effects of training and practice on spatial performance also lend support to the Sherman Hypothesis. Results, in some instances, tend to be variable depending on the type and amount of training provided. Gibson (1953) reported significant improvement through training and practice in various apsects of visual space, i.e., area and extent, angle, depth and distance and to some degree, visual speed of an object. Goldstein and Chance (1965) found that over a series of sixty-eight embedded figures, significant sex-related differences were reduced to almost zero in a college population. Males reduced their discovery times by sixty-five percent and females obtained a seventy-four percent reduction. Gill, Herdtner and Lough (1968) investigated perceptual differences and academic achievement in nursery school children on the basis of sex, race and socioeconomic class. Half the children were given special exercises to enhance bodily awareness. The special exercises were found to significantly improve performance on three of five tests of perceptual ability. Perceptual performance was more highly correlated with predicted academic success for girls than boys. While race was not a significant factor, socioeconomic class was a significant effect. Lower class children were found to be more poorly developed in perceptual abilities than middle class children. McGee (1978b) examined the influence of training and practice on sex-related differences in Mental Rotation Test scores. Subjects were given the Mental Rotations Test on two occasions separated by an interval of three weeks and received unobtrusive training on the task between testing sessions. Significant differences favoring males were found within and across trials, although both males and females significantly improved their scores on the second trial. McGee concluded that there was no evidence for a differential response to training and practice by females. However, considering the amount of training and practice that was given in the two previous studies, training in this study was at best, superficial, as the actual training session consisted of an hour long lecture on spatial ability. Jones (1972) investigated the perceptual characteristics of English female physical education students using both the Embedded Figures Test and the Rod and Frame Test. She found that the female athletes obtained scores similar to those reported for American males in field independence-dependence and that the female athletes were more field independent than American females. Findings from Gill et al. (1968) and Jones (1972) suggest that experience in one sensory modality could transfer to, and enhance skills in another modality. This concept should be interpreted with some caution as research is meager in this area and particularly with regard to the Jones study, other factors, i.e., sex-role identification, might be implicated. For example, Spence and Helmreich (1978) found that varsity athletic students along with other high achieving females were overrepresented in the Masculin and Androgenous categories of her Masculinity-Femininity scale.

Sex-Typing and Sex-Roles

While findings from training studies give an indication of the role of relevant training and practice in determining spatial performance, other factors cannot be ignored. Spatial skill in this culture is sex-typed male (Stein and Smithells 1969) and females have been shown to have lower achievement in academic areas not considered sex-appropriate (Kagan 1964; Stein and Bailey 1973). Identification with a sex-role, parental identification, sex-role standards, achievement motivation and socioeconomic status have all been identified as important components influencing cognitive performance. Milton (1957) found that males or females scoring high on masculinity scales demonstrated significantly better problem solving skills than males or females scoring high on femininity scales. Bieri (1960) demonstrated that females who identified with their fathers scored higher on tests of field independence than females identifying with their mothers. Spence and Helmreich (1978) also noted in their studies, fathers tended to play a more important role in the development of his daughter's achievement motivation than did the mother. Kagan (1964) was the first to investigate the proposition that achievement in academic areas could be better predicted on the basis of the subject's perception of sex-linked appropriateness of the role (sex-role standard), than on the basis of gender or personal preference for a particular academic area. Dwyer (1974) examined the relationship between sex-role standards and actual academic achievement and found that achievement was more a function of the subject's perception of the tasks being sex-role appropriate or inappropriate than gender, personal preference for an academic area or of individual preference for the masculine or feminine role. Socioeconomic status appeared to play an important role in the development of sex-role standards (Paulsen and Johnson 1983) and was found also to be a significant factor in the development of perceptual skills (Gill, Herdtner and Lough 1968).

CHAPTER 3

HYPOTHESES AND PROPOSED STUDY

Summary of Literature

While there is general agreement that the spatial factor is a multidimensional trait, there is presently no clear consensus as to the total number, names or definitions of all the factors that are components of this trait. However, one factor, nonanalytic spatial visualization, has been identified, studied and defined. This factor involves the ability to mentally rotate an object in space without the aid of verbal mediation. Further a test has been developed and modified into a paper-pencil test which gives a relatively pure measure of this skill. The test is reliable, correlates highly with other measures of spatial ability and has a low association with measures of verbal ability.

The spatial visualization factor emerges as a distinct ability at adolescence and sex-related differences favoring males have been well documented. Spatial visualization skill has been related to mathematical performance on the basis of factor analytic studies and also on the basis of the parallel development of a male advantage in mathematics at adolescence. However, there is not a sufficient data base to accept or reject a relationship between the two skills and more correlational data is needed.

There are two major theories accounting for the origin of sex-related differences found in this skill. The biological approach suggests several hypotheses, one of which is the male advantage may be due to a sex-linked recessive gene. A second hypothesis suggests that spatial ability is androgen-limited in combination with a recessive gene and a third hypothesis suggests that it may be due to differential lateralization of the cerebral hemispheres.

Sherman alternatively proposes that sex-related differences are due mainly to a process of differential socialization exaggerating small innate differences between the two sexes. She emphasizes the importance of early acquisition of this skill in the later development of abstract cognitive processes. This view is shared by many developmentalists who believe that the acquisition of higher order abstract cognitive skills depends on a hierarchical progression, moving from concrete actions through a process that produces an internalized manipulation of abstract symbols. Cross-cultural studies of spatial ability tend to support the Sherman Hypothesis as do the few studies investigating the effects of training and practice in this particular area. Finally other factors including sex-role identification, parental identification, sex-role standards, socioeconomic status and achievement motivation are believed to play an important role in the development of spatial visualization skills.

Sherman Hypothesis and Derived Hypotheses

The intent of this study was to gather information relating to the Sherman Hypothesis by examining the effects of two types of specialized training on spatial visualization performance and to investigate the relationship between spatial visualization performance and mathematic performance. The Sherman Hypothesis can be restated in the following terms;

1. Spatial visualization ability appears to be an important component of mathematical problem solving ability and as such, may be contributing to findings of sex-related differences in mathematics.
2. Spatial skills can be learned.
3. Acquisition of spatial skills early in development may be an important factor in the later development of abstract problem solving ability in mathematics.
4. In this culture, males are more likely to acquire superior spatial skills and thereby, better mathematic skills because they have a greater exposure to activities which develop spatial skills throughout their development.

Based on this summation three hypotheses were formulated;

1.
   a. Long term specialized training in the kinesthetic modality, defined as long term training in gymnastics, will significantly enhance performance on spatial visualization and mathematic tests.
   b. Significant sex-related differences favoring males in both spatial and mathematic performance will only be found in groups not having specialized gymnastic training.

II.

a. Long term specialized training and practice in spatial relations will significantly increase scores on a test of spatial visualization.

b. Females will demonstrate a differential response to training and practice and are expected to demonstrate a significantly greater rate of improvement than males.

III.

a. There will be a strong positive relationship between scores on a test of spatial visualization and mathematic scores.

Proposed Studies

The investigation was divided into three parts and data was to be gathered from three populations of college students.

Study One

This study was designed to test Hypothesis I. Scores obtained on a test of spatial visualization and a mathematic test by a group of highly trained athletes would be compared to those obtained by a control group having no specialized training. Gymnasts were selected for the training condition because the skills developed in this sport (balance, kinesthetic sense and exploration of space) seemed relevant to the activities hypothesized by Sherman and others to develop spatial skills. In addition, persons involved in this activity usually begin training early in development and spend many years in training. Another important consideration was the fact that both sexes are encouraged to participate in this sport. The gymnast group and the control group would be matched on a number of variables believed to be important in comparisons by sex. They included age, ethnic group, socioeconomic status, sex-role identification, parental identification and an achievement motivation score. Information would also be gathered on years of involvement and training in other sports, dance, art, drafting courses and mathematic background.

Study Two

The second study was designed to test the hypothesis that spatial skills could be learned, Hypothesis II. Subjects for this study would be recruited from the first year class of students enrolled in the College of Architecture. This population was selected as all students are given intensive training in spatial relations during the first year of study. Testing sessions would be administered at the beginning and end of one semester and would include a mathematics test and two administrations of the same spatial visualization test. Although participants in this study would be asked to complete all questionnaires required of study one participants, no matching procedures were planned as subjects in this study would serve as their own controls.

Study Three

This study was designed to obtain information on the relationship between spatial visualization performance and mathematic problem solving performance. Spatial visualization scores and mathematic scores obtained from all subjects in the previous two studies would be compiled and compared.

CHAPTER 4

METHOD

Subjects

A total of (205) college students were recruited from students enrolled at the University of Arizona and Arizona State University. Data for the final analysis were available from (166) students. The reasons for the loss of 39 subjects will be detailed more specifically in the individual descriptions of each study.

Subjects for the gymnast group were contacted with the assistance of the gymnastic coaches at the two schools. Subjects for the control group were recruited from the Department of Psychology at the University of Arizona by classroom announcements and notices posted throughout the Psychology Building. Subjects in the College of Architecture were recruited during class periods.

In each instance students were informed that the study involved an investigation of spatial ability and other cognitive abilities, the number and type of tests and questionnaires to be used and an estimate of the time required to complete the battery. Students were also advised that participation was entirely voluntary and assured anonymity of response. If interested, students would be given their spatial visualization scores and the mean spatial scores of males and females as determined by Wilson et al. (1975) for comparison. All subjects were required to have a command of the English language.

Study One

The gymnast group recruited from two university gymnastic teams consisted of 29 individuals. Eleven persons having long term training in gymnastics were found in the control group and their data were subsequently transferred to the gymnast group bringing the final total in the gymnast group to 40 subjects (15 males and 25 females). The gymnasts were paid a small fee (three dollars) for participation in the study. The subjects for the control group were recruited from several Introductory Psychology courses during the two summer sessions of 1981. They were not financially reimbursed but were given extra-credit points for their participation according to guidelines set by the Department of Psychology at the University of Arizona. The original control group contained 72 individuals; eleven having gymnastic training were moved into the gymnast group. Two additional subjects were eliminated entirely from the study because one failed to follow directions on the spatial visualization test (marked only one choice on each item rather than two as directed) and the other subject did not answer any of the mathematic items on the Otis Test of Mental Abilities. The final number of subjects in the control group totaled 59 individuals (24 males and 35 females).

Study Two

First year architecture students were recruited twice, at the beginning of each of the two class periods reserved for pre-testing and post-testing. A total of 104 subjects (74 males and 30 females) took part in the first testing session while only 75 subjects

(56 males and 19 females) participated in the second testing session. This loss was assumed to be due in large part to the normal attrition rate encountered in this area of study during the first year of study. The number of subjects in this group was further reduced to 67 subjects (49 males and 18 females) for the following reasons and in order of greatest loss, subject participated in only one testing session (either pretest or post-test), failed to follow directions on the spatial visualization test or did not answer any of the mathematic items on the Otis S-A Test of Mental Abilities. Architectural subjects were not reimbursed in any way but were given their scores on the two tests of spatial visualization if so requested.

Study Three

Spatial visualization scores and mathematic scores from subjects in the previous two studies were used for comparisons. Since the architectural students had two spatial scores and training between the times the scores were collected, the spatial score (SMMRI) from the pretest session was used in the final analysis.

Measures

All subjects were given the same battery of tests and measurements. The measurements included the following tests and questionnaires.

1. Shepard-Metzler Mental Rotations
   A Test of Three Dimensional Spatial
   Visualization. S.G. Vandenberg (1978)

2. Otis S-A Test of Mental Abilities, Higher Examination: Form A

3. Seventeen Item Mathematic Test Otis S-A Test of Mental Abilities, Higher Examination: Form A

4. Personal Attributes Questionnaire Spence, Helmreich and Stapp (1974)

5. Work and Family Orientation Questionnaire. Helmreich and Spence (1978)

6. Parental Attitudes Questionnaire Spence and Helmreich (1978)

7. Experience and Family Information Questionnaire (modified) Spence and Helmreich (1978)

Socioeconomic status was ascertained using information gathered from the Experience and Family Information Questionnaire and was based on the Hollingshead and Redlich Two Factor Index of Social Position Scale (Hollingshead 1957). Classification was based on data from the male head of household except in those cases where there was no male present. Classification was then based on the major supporting member.

<u>Shepard-Metzler Mental Rotations (SMMR)</u>

This test was based on the work of Roger Shepard (Shepard and Metzler 1971) and involves the discrimination of spatially transformed objects. Vandenberg and Kuse (1978) developed a paper-pencil test from the original computer-generated drawings used in the experiments. The Mental Rotations Test contains twenty items in five sets of four items. Each item consists of a criterion figure, two correct choices and two distractor choices. Correct choices are identical to the criterion figure but are shown in a rotated position (some multiple of 20°). Half of the distractor choices are rotated mirror images of the criterion figure and the other half are rotated images of other criterion figures. Vandenberg and his associates administered this test to large population samples and obtained substantial internal consistency (Kuder-Richardson 20 = .88) and Test-Retest reliability (.83)(Wilson et al. 1975; Kuse 1977).

Vandenberg and Kuse (1978) found the Mental Rotations Test correlated strongly with other tests of mental ability, but that it showed low correlations with test of verbal ability (Table 1). Wilson et al. (1975) obtained pronounced sex-related differences in an ethnically diverse group of 2,498 individuals tested in Hawaii (Figure 1).

The test was further revised for this study as the Vandenberg version seemed confusing due to close spacing of the items. His version consisted of three pages, with seven items spaced on each of the first two pages and six items spaced on the last. The format was changed by spacing five items on a page thus increasing the number of pages to four. Each set of items was numbered and the four answer choices labelled (a to d) to facilitate the use of answer sheets.

Seventeen-Item Mathematic Test (Otis Math)

Two scores were collected as measures of mathematic performance, a college entrance quantitative score from either the American College Test (ACT) or the Scholastic Achievement Test (SAT) and a score extracted from seventeen mathematic items in the Otis S-A Test of Mental Abilities. However, numerous subjects were unable to provide college entrance scores and the seventeen-item test score was used as the major measure of mathematic performance.

Personal Attributes Questionnaire (PAQ)

The instrument used to assess sex-role identification was the short form version of the Personal Attributes Questionnaire (PAQ) developed by Spence, Helmreich and Stapp (1974). This questionnaire is divided into three separate scales labelled Masculinity (M scale), Femininity (F scale) and Masculinity-Femininity (M-F scale). The researchers intended to use a dualistic approach in developing this instrument, conceptualizing masculinity and femininity as separate aspects of the personality that vary more or less independently. However, their research findings on the M-F scale also provided support for the use of a bipolar model and indicated that the use of the M-F scale might yield significant information not available in the other two scales. The researchers decided to retain the M-F scale "despite the conceptual embarrassment of having to embrace simultaneously a dualistic and a bipolar model of masculinity and femininity." Items included in the M scale are defined and measured as a constellation of socially desirable personal attributes denoting an instrumental or agentic orientation. Items relating to femininity are defined and measured in terms of socially desirable traits reflecting a sense of community and interpersonal orientation. Items on the M-F scale differ in that they consist of characteristics whose social desirability appears to vary in the two sexes (i.e., aggressiveness is judged to be desirable in males and nonaggressiveness desirable in females). Both agentic and communal characteristics are included in the M-F scale, many of the communal characteristics seeming to refer to emotional vulnerability (i.e., feelings easily hurt).

The short form of the PAQ is composed of twenty-four bipolar items, eight items per scale, describing personal characteristics on each of which, respondents are to rate themselves on a five point scale. Each item is scored 0 to 4, a high score on the M and M-F scales indicating an extreme masculine response and a high score on the F scale indicating an extreme feminine response. Total scores are obtained on each scale by adding the individual's score on the eight items assigned to each scale. The range of possible values for each of the three scales is 0 to 32. Using M and F scores individuals are then classified into one of four groups. This is done by determining the median scores on M and F scales for the total sample (males and females combined). Individuals are then classified by means of a 2 by 2 table according to their position above or below the median (Table 2). These four groups have been labelled Androgenous (high on M and F), Masculine (high on M and low on F, the conventional male or cross-sex female), Feminine (low on M and high on F, the conventional female or cross-sex male) and undifferentiated (low on M and F). The four-way classification may be expanded further into an eight-way classification by dividing individuals in each of the four cells into those falling above and below the median on the M-F scale.

Table 2. Scheme for Classifying Individuals on Masculinity and Femininity Scores by a Median Split.

	MASCULINITY	
	Above Median	Below Median
Femininity: Above Median	Androgenous	Feminine
Femininity: Below Median	Masculine	Undifferentiated

From Spence and Helmreich (1978; p. 35).

Spence et al. (1978) have established two sets of normative data for the purpose of classifying subjects on the short form of the PAQ. The first set is based on the rounded mean of the medians of high school males and females (the mean of medians was used rather than the median of the total sample because of unequal numbers of males and females). A second set of norms was established in a similar manner using data from 715 college students. The high school norms were, M scale=20, F scale=23, M-F scale=15. The college norms were M scale=21, F scale=23, M-F scale=15. Spence et al. (1978) believe the use of their general college norms are appropriate in most investigations especially in investigations using a small random sample of college students. In instances where there is question as to the appropriateness of the norms, they suggest the researcher use both the general college norms and norms obtained from the research population to calculate categorical scores. Medians from the combined research population in this study were calculated to check agreement with the general college norms.

Work and Family Orientation Questionnaire (WOFO)

The Work and Family Orientation Questionnaire (WOFO) developed by Helmreich and Spence (1978) is a thirty-two item measure of achievement motivation and attitudes towards family and career. The questionnaire is divided into two parts. The first part contains twenty-three achievement items divided into four factor analytically derived scales labelled Mastery, Work Orientation, Competiveness, and Personal Unconcern. Items are answered on a five-point Likert scale ranging from strongly agree to strongly disagree. Each item is scored from 0 to 4.

The second part contains nine items, six items deal with attitudes towards job advancement, pay, prestige and recognition for self and for spouse. The remaining three items, which are more appropriate for younger populations, ask the minimum amount of education acceptable, the relative importance of marriage and career and the number of children desired. These items are not scaled but are retained for use as control or classification variables if needed. The last nine items were not scored in this study and an achievement motivation score was obtained using only the first twenty-three items of the WOFO.

Parental Attitudes Questionnaire

The Parental Attitudes Questionnaire developed by Spence and Helmreich (1978) consists of fifty-eight items inquiring about parent's attitudes and behaviors or the family atmosphere. The first eight items contain statements about both parents or the family as a whole. These are followed by twenty-five statements about the mother and a parallel set of twenty-five statements about the father. Each item is accompanied by a five-point scale ranging from very characteristic to very characteristic. The last section, and the only section scored in this study, contains five items designed to determine the parent to whom the respondent feels closest or most resembles in ideals or personality, as well as the degree of parental agreement about child rearing. These items, each accompanied by five response alternatives were scored separately and with the exception of the question about child rearing were used to provide a measure of parent identification. Respondents were asked to complete this section only if they came from an intact family or had parent substitutes throughout their rearing. Five categories of response were possible, identifies with father, with mother, with both parents equally, identifies with neither or no identification possible due to absence of one parent or both.

Experience and Family Information Questionnaire

This questionnaire was designed by Spence and Helmreich (1978) to obtain information on a number of variables including sex, age, ethnic group, family status, birth order, religion and parent's occupation and educational level. It was modified to include questions on type and amount of training in gymnastics and other sports, dance, art, drafting courses, mathematical background, handedness, college major and college entrance scores on either the ACT or SAT.

Procedure

Study One

Approximately ninety-nine (99) subjects took part in this study. The measurements were administered by the female researcher, a graduate student in psychology, and a female research assistant, an undergraduate student, over a series of sessions. The groups in the sessions ranged in size from three individuals to twenty-five. One group of gymnasts and all the control subjects were given the battery of tests and measurements by the female researcher during the Spring and Summer semesters of 1981 at the University of Arizona. The research assistant conducted a testing session for a second group of gymnasts at Arizona State University during the Fall semester of 1981.

All testing sessions were conducted in the same manner; the instructions were read from a written text and the order of presentation was not varied. At the beginning of each session subjects were advised briefly of the nature of the investigation, told the number and type of tests and questionnaires to be given and were given an estimate of the time required to complete the battery (approximately ninety minutes). Subjects were encouraged to ask questions about the procedure and confidentiality issues and allowed to withdraw from the study at that time if they so chose. In order to insure confidentiality, subjects were instructed to use a code consisting of their initials, or a false set of initials, their birthdate and the letters M or F to denote sex (i.e., LL-91461-M). Subjects were given individual copies of the Experience and Family Information Questionnaire to fill out and were instructed in detail on completing this form. Subjects next were given a booklet containing all the remaining tests and questionnaires, excepting the Otis S-A Test of Mental Abilities (Otis). The measurements were bound into the booklet in the order of, Shepard-Metzler Mental Rotations Test (SMMR), Personal Attributes Questionnaire (PAQ), Work and Family Orientation Questionnaire (WOFO) and Parental Attitudes Questionnaire. Subjects also were given an answer sheet which provided response choices for all the measurements in the booklet, including response choices for the Otis. Following completion of the Experience and Family Information Questionnaire, standard instructions relating to the SMMR and the use of the answer sheet were given. Subjects were then given a ten minute timed-test on the SMMR. After the SMMR was completed, subjects were told to put the booklet aside and copies of the Otis were distributed. Again standard instructions relating to the Otis and the use of the answer sheets were read aloud. Subjects were told they could begin to work on the remaining questionnaires in the booklet, in the order given, if they finished the Otis before time was called.

Subjects were given a thirty minute timed-test on the Otis. At the end of the test all copies of the Otis were collected and subjects were instructed to complete the remaining questionnaires. Subjects were monitored throughout the remainder of the session to insure that no one returned to the spatial test. Reimbursement by fee or by extra credit class points was given at the end of the session as subjects turned in the test material. All tests and questionnaires were hand scored by either the researcher or the research assistant and rechecked by the researcher.

Study Two

Subjects for the second study were drawn from the 1981 first year class of architecture students enrolled in the course Graphic Communications. Two testing sessions, pretraining and post-training, were set up with the cooperation of the course instructor who donated two full class periods to the study. Testing during both sessions was administered by the research assistant using the same battery of instruments used in Study One. However, procedure and order of presentation varied somewhat due to the constraint of fifty minute class periods. Subjects were recruited at the beginning of each test session and as before, advised of the nature of the investigation, the number and type of measurements and their rights concerning voluntary participation and confidentiality. Students not wishing to participate were excused from class that period. During the first testing session, subjects were given the SMMR and the Otis, using the same time limits as in the previous study, ten minutes and thirty minutes respectively. At the end of the semester subjects were recruited from the same class and given the SMMR, the Experience and Family Information Questionnaire, the Personal Attributes Questionnaire and the Work and Family Orientation Questionnaire. As in the previous study, subjects in both testing sessions were asked to use a consistent code system for identification, except it was not suggested that they could use a set of false initials. Data packets were formed from subjects completing both administrations of the SMMR and all other measurements. In this study the researcher and the research assistant scored only the two spatial tests and the Otis, obtaining two scores of spatial performance, a mathematic score and an IQ score for sixty-seven subjects.

Study Three

Spatial visualization scores and mathematic scores were obtained from subject data in the two previous studies. The single SMMR score of Study One participants, the pretraining SMMR score (SMMR-I) of Study Two subjects and mathematic scores from the Otis and college entrance examinations (ACT or SAT) were used to investigate the relationship between spatial visualization performance and mathematic performance.

Results

Study One

Descriptive statistics on all variables were obtained on the ninety-nine (99) subjects participating in this study on the basis of category and sex. The four groups consisted of 15 male gymnasts, 25 female gymnasts, 24 male control subjects and 35 female control subjects. Subjects were classified on the sex-role identification score using Spence and Helmreich's (1978) general college norms. Norms were also calculated using the rounded mean of the medians of the research population (males and females combined). Norms from the research population varied from the general college norms by one point on the M scale and the M-F scale and the general college norms were considered valid for this population. The research norms were M scale=22, M-F scale=16 and F scale=23. The general college norms used were M scale=21, M-F scale=15 and F scale=23. The statistics were reported in terms of mean, standard deviation, median and mode. Scores will be reported in the text in terms of the mean, standard deviation and where appropriate, absolute and relative frequencies. The mean scores obtained by this population for the variables, age, IQ score, mathematic background (MBG), training, other sports (TOS), sports involvement (SI) and achievement motivation (WOFO) are shown in Table 3. Absolute and relative frequencies were obtained for ethnic group, socioeconomic status, sex-role identification and parental identification (Appendix A, Tables A1 to A4). The gymnast group averaged 5.5 years of gymnastic training while members of the control group had none (0 years). Subjects typically were white and belonged to the middle to upper class divisions of Hollingshead's categories of socioeconomic class (classes, 1, 2 and 3). Males tended to identify with the masculine role and father, while females tended to identify with the androgenous sex-role and mother.

Table 3. Mean Scores by Category, Sex on Variables Selected for Matching: Total Population.

CATEGORY	n	Age	IQ SCORE	MATHEMATIC BACKGROUND	SPORTS * TRAINING	SPORTS * INVOLVEMENT	ACHIEVEMENT MOTIVATION
GYMNAST							
Males	15	20.9	115.5	5.8	9.0	15.7	64.3
Females	25	21.3	107.6	4.1	9.8	6.3	64.3
CONTROL							
Males	24	24.7	116.7	5.5	10.0	21.2	63.5
Females	35	24.9	111.8	4.1	5.7	5.5	63.3

*Does not include gymnastic training.

Fourteen subjects from each group were then matched as closely as possible on the following variables, age, IQ, mathematic background, the two sports background scores (SI and TOS) and the achievement motivation score (Table 4). Absolute and relative frequencies were obtained for ethnic group, socioeconomic status and the two identification scores which are reported in Appendix A, Tables A5 to A8. The number of subjects per cell was reduced to fourteen because one male gymnast did not answer any of the questionnaires which effectively eliminated his data from the matched-groups study.

Spatial visualization scores and mathematic scores were tested using separate 2 by 2 analysis of variance, ANOVA, (category x sex of subject). The alpha level was set a priori at .05. The hypothesis that individuals having specialized training in gymnastics would perform significantly higher on tests of spatial visualization and mathematics was not confirmed. There were no significant differences in spatial visualization scores across categories, df 1, F(.699), $p > .05$, see Table 5. However, there were significant differences found across sex of subject. Males, overall, obtained significantly higher scores on the spatial visualization test than did females, df 1, F(5.662), $p < .05$ (Table 5). No significant differences were found in mathematic performance by category or by sex, df 1, F(1.137), $p > .05$, see Table 6 for mean scores.

Table 4. Matched-Group Mean Scores by Category, Sex, for Selected Variables.

CATEGORY	AGE	IQ	MATHEMATIC BACKGROUND	SPORTS* TRAINING	SPORTS* INVOLVEMENT	WOFO
<u>GYMNAST</u>						
Males	21.0	115.4	5.6	9.5	16.4	64.3
Females	20.4	113.7	4.1	11.1	7.1	67.6
GYMNAST						
Combined Means	20.7	114.5	4.9	10.3	11.8	65.9
SD	3.1	9.2	1.8	12.0	17.0	8.7
<u>CONTROL</u>						
Males	21.9	114.2	6.1	11.7	22.5	62.9
Females	20.8	114.8	4.3	6.5	7.6	61.6
CONTROL						
Combined Means	21.4	114.5	5.9	9.1	15.0	62.3
SD	3.1	11.5	1.8	10.3	18.2	7.7

* does not include gymnastic training.

Table 5. Mean Scores on Spatial Visualization Test by Category and by Sex for Matched-Groups.

SUBJECTS	n	SPATIAL VISUALIZATION SCORE
CATEGORY		
Gymnasts	28	25.071
Control	28	23.500
SEX		
Males	28	26.571*
Females	28	22.000

* = Significant difference.

Table 6. Mean Scores on Otis 17-Item Mathematic Test by Category and by Sex, Matched-Groups.

GROUPS	n	17-ITEM MATH SCORE
CATEGORY		
Gymnast	28	10.714
Control	28	10.785
SEX		
Males	28	11.392
Females	28	10.107

A strength of association measure omega^2 (ω^2) was calculated for the significant effect of sex using data from the matched-group analysis of variance. The results indicated that only 8% of the variance in spatial performance was accounted for by sex of subject. Since there were variables on which the subjects appeared to vary to a large degree, all variables were tested for significant differences (by category and by sex) using oneway ANOVAs of the matched-group data. No significant differences were found by category while two variables, mathematic background and sports involvement, differed significantly by sex. An analysis of covariance was performed (SMMR by category and by sex with covariates, mathematic background and sports involvement) on both the total population and the matched groups to determine the influence of those two variables on spatial performance. Sex of subject and the two covariates had a significant effect in the analysis of the total population, but only sex of subject was significant in the matched-groups analysis (Table 7). Finally, an effort was made to determine if any of the variables gathered in this investigation correlated more strongly with spatial performance than did sex of subject. Accordingly, a correlation matrix was obtained using data from all 99 subjects involved in this study. In this analysis, sex of subject accounted for 16% of the variance in spatial scores, $r=-.41$, $r^2=.16$ while IQ score accounted for 18% of the variance in spatial scores, $r=.42$, $r^2=.18$. Other variables had correlations ranging from $r=.19$ to $r=.34$ (see Table 8). Many of these variables related to sociocultural factors,

Table 7. Analysis of Covariance: Total Population and Matched-Groups analysis, SMMR by Sex and by Category, with Mathematic Background and Sports Involvement.

SOURCE	df	F	p
Total Population			
Covariates			
SI	1	4.068	.047*
Math BG	1	4.246	.042*
Main Effects			
Sex	1	4.054	.049*
Category	1	.284	.595
Matched-Groups			
Covariates			
SI	1	.488	.488
Math BG	1	.583	.499
Main Effects			
Sex	1	4.054	.049*
Category	1	.284	.595

* = Significant difference.

Table 8. Correlation Coefficients, Spatial Scores and Selected Variables.

VARIABLES	IQ	MATH SCORE	SPATIAL
Category	.14	.05	.06
Sex	-.26*	-.40**	-.41**
SES	-.23	-.23*	-.04
MBG	.18	.27*	.21*
TOS	.25	.26*	.19*
SI	.22	.30**	.20*
M-F Scale	.20*	.20*	.34**
M Scale	.20*	.16	.16
F Scale	-.06	-.13	-.29*
PID	-.07	-.11	-.21
WOFO	.24	.20*	.31*
IQ		.87**†	.42
Math			.49**

*p .05.

**p .001.

† The correlation coefficient between IQ and mathematic score is confounded as the two measures are not independent. The mathematic score was based on 17 meathematic items derived from the Otis S-A Test of Mental Abilities.

i.e., sex-role identification, parental identification, and achievement motivation. In this analysis, the correlation between scores on the spatial visualization test and scores on the mathematic test was $r=.49$, $r^2=.24$.

Study Two

A mixed-model analysis of variance (sex of subject x repeated measures) was used to evaluate the pretraining and post-training data obtained from the sixty-seven architecture subjects (49 males and 18 females) participating in this study. Because there was an unequal number of males and females, the same analytic procedure also was carried out on an equal number of males and females via a process of random elimination of male subjects. Results from both analyses were similar and supported the second hypothesis, that spatial skills can be learned or improved as post-training scores on the SMMR were significantly higher than pretraining scores, df 1, $F(58.38)$, $p < .05$, from the analysis using all subjects and df 1, $F(45.04)$, $p < .05$, in the analysis using equal numbers of males and females. The mean pretraining and post-training scores on the SMMR for the total population were 28.5 and 34.2 respectively, and in the analysis using equal numbers of subjects, the pretraining mean score was 27.7 while the post-training mean score was 33.6.

The second part of this hypothesis was not confirmed. Although there was a small insignificant trend on the part of females to show a differential response to training, males achieved significantly higher scores over both testing sessions, df 1, $F(16.07)$,

$p < .05$, in the total population analysis and df 1, F(16.08), $p < .05$, in the equal number of subjects analysis (see Table 10).

Table 9. Mean SMMR Scores by Sex, Pretraining and Post-Training, Achieved by All Subjects and by Equal Numbers of Males and Females.

GROUP	n	PRETRAINING	POST-TRAINING
All Subjects			
Males	48	30.428	35.816
Females	18	23.444	29.889
Combined		28.552	34.223
Equal Numbers by Sex			
Males	18	31.944	37.278
Females	18	23.444	29.889
Combined		27.694	33.583

SMMR total score = 40.

In fact, in the analysis using equal numbers of males and females, males came very close to achieving a perfect response record, while females did not quite reach the males' pretraining level with their post-training scores. The interaction was not significant in either analysis.

Study Three

Comparisons of spatial performance and mathematic performance used the single score on the SMMR test obtained by study one subjects and the pretraining score on the SMMR obtained by study two subjects. Since only 53 subjects reported college entrance scores, the Otis 17-item mathematic test was used as the major measurement of mathematic performance. Pearson's correlational technique was used to investigate the relationship between spatial performance and mathematic performance and Pearson's r was computed on all three mathematic scores (Otis 17-item mathematic test, ACT score and SAT score) and the spatial score from the SMMR test. The hypothesis favoring a strong positive relationship between scores on the spatial visualization test and the mathematic test was not essentially confirmed. Although a positive relationship was established, the correlation coefficients were in the moderate range. The analysis using all 166 subjects produced a correlation coefficient of $r=.33$, $p < .05$. Separate analyses by sex indicated that the relationship was somewhat stronger for females ($r=.30$, $p < .05$) than for males ($r=.20$, $p < .05$). This was considered an unusual finding as factor analytic studies have generally indicated that the space factor is relevant for males in mathematic performance but not for females (Thurstone 1938, 1941; Werdelin 1961). The relationship between the spatial score and the two college entrance quantitative scores was stronger, the correlation coefficient obtained for ACT scores was $r=.38$ and for SAT scores $r=.49$. As previously mentioned in the discussion of study one results, an analysis using the SMMR scores and Otis mathematic scores of the 99 subjects (gymnasts and control subjects combined) produced a correlation coefficient of $r=.49$. The results of each analysis are presented in Table 10.

Table 10. Pearson Correlation Coefficient and Coefficient of Determination for SMMR and Mathematic Scores.

ANALYSIS	n	r	r^2	p
Otis Mathematic Test				
1. Overall Population	166	.33	.11	.001
a. Males	88	.20	.04	.029
b. Females	78	.30	.09	.004
2. Study One	99	.49	.24	.001
3. ACT Scores	28	.38	.15	.025
4. SAT Scores	25	.49	.24	.005

Summary of Results

Hypothesis I

The first hypothesis was not supported by the results of study one. Gymnastic training did not appear to enhance spatial visualization performance or mathematic performance for the members of that group. Overall, males achieved significantly higher scores on the SMMR test than females. In addition, it had been predicted that significant sex-related differences in mathematic performance would be found only in the control group. In this study, no significant sex-related differences in mathematic performance were found in any group. A strength of association measure (ω^2) indicated that only 8% of the variance in spatial scores was accounted for by sex of subject.

This measure was obtained from a study which had attempted to rigorously control variables associated with sex bias effects. In contrast, the coefficient of determination, obtained from analyses in which no control of variables had been exerted, indicated that sex of subject accounted for 11% to 24% of the variance in spatial scores.

Hypothesis II

The first portion of Hypothesis II was confirmed as scores on the SMMR significantly improved across both sexes following training in spatial relations. However, the second part of Hypothesis II was not confirmed. While females showed a significant rate of improvement in spatial scores from pretraining to post-training and though they gained slightly more than males, they did not demonstrate a significant differential response to training. Significant sex-related differences in spatial performance favoring males were still observed in the post-training scores. Female post-training scores were slightly below scores achieved by males in the pretraining session.

Hypothesis III

Results in the third study were equivocal. A strong positive relationship between spatial and mathematic scores had been predicted. Significant positive correlations were found but they were in the moderate range ($r=.33$ to $r=.49$). Surprisingly, the correlation between spatial and mathematic performance was found to be higher for females ($r=.30$) than for males ($r=.20$).

CHAPTER 5

DISCUSSION

Study One

The intention of this study was to create an experimental model in which the spatial performance of a group of males and females selected for life experiences believed to enhance spatial skills would be compared to the spatial performance of a group without those experiences. It was predicted that the selected group, gymnasts, would obtain significantly higher scores on a spatial visualization test than the group without training. It was further postulated that differences in spatial performance would be related to differences in mathematic problem solving skills and that the gymnast group would also achieve higher mathematic scores than the control group. Sex-related differences in both spatial visualization and mathematic performance were predicted to occur only in the control group.

Since it is not possible to randomly assign or to eliminate the subject variable sex and because a subject's reaction can be due to a sex bias rather than to any inherent quality of sex (Wittig 1979), both groups were carefully matched on a number of variables reliably reported to be associated with sex bias. It was expected that this matching process would eliminate most of the confounding variables relating to sex and several possibilities would then exist. Differences, if found only between groups, could be more directly related to differences in life experience or training. On the other hand, if differences were found only between the two sexes, a better estimate of the impact of sex of subject on spatial visualization performance could be gained. Another possibility would be evidence of some sort of interaction between training and sex of subject. In fact, the findings of this investigation indicated that sex of subject was the only significant factor associated with differences in spatial scores. While gymnasts as a group achieved a slightly higher mean score on the spatial visualization test than did the control group, the difference was not statistically significant and the difference was entirely due to the male gymnasts' superior spatial performance. Males invariably achieved higher scores on the spatial visualization test than did females across all categories of subjects (gymnast, control, architecture) included in the whole investigation. Additionally, no sex-related differences were found in mathematic performance in any of the group comparisons. This was a contradictory result with respect to other studies in this area (i.e., Benbow and Stanley 1980). Most importantly a strength of association measure indicated that the variable sex of subject accounted for only 8% of the variance in spatial visualization scores.

The finding of sex of subject as the only statistically significant factor contributing to spatial performance in this study is somewhat misleading and requires explanation. One obvious conclusion that could be formed from these results is that this investigation did not confirm Sherman's primary assumption, early childhood experiences have an effect on the development of abstract cognitive functions, specifically the development of spatial skills. It had been assumed that members of the college gymnastic teams would have long term experience in gymnastics extending back to childhood. This was not the case. When the data was compiled it was found on the average both males and females had 5.5 years of gymnastic training. Since the mean age of this group was 21 years, this meant most of the members of this group began training at age 15 or 16, several years past the time sex-related differences in spatial performance begin to be observed. This was disappointing but was an unavoidable situation given the difficulty of finding sufficient numbers of subjects having this type of training. Therefore, it was concluded that in this regard the Sherman Hypothesis was not effectively tested. No conclusions about the effects of early physical training on perceptual learning or the development of spatial skills can be made. Although reduced to speculation, as there is no knowledge of the gymnasts' spatial skills prior to training or sufficient information as how life experiences of both groups varied, the distribution of scores across category and sex is intriguing and suggests the need for further investigation. Table 11 shows the mean scores of spatial visualization scores by category, by sex and by category and sex of the matched group analysis. Male gymnasts were by far the most spatially adept group exceeding even male control subjects although the difference between these two did not quite reach a significant level (t, $1.437 < t$, 1.706, $\alpha = .05$). Participation in this activity possibly could involve a selection process in that only individuals with inherent high spatial skills do well and continue in this sport. However, this does not account for the lesser spatial skills of the female gymnasts. What is needed is a longitudinal study of the impact of physical training on the development of spatial skills in males and females.

Table 11. Spatial Visualization Mean Scores, by Category, by Sex, and by Category and Sex, Matched-Group Analysis.

GROUPS	n	$\bar{X}$
Gymnast	28	25.07
Control	28	23.50
Males	28	26.57*
Females	28	22.00
Gymnasts		
Males	14	28.7
Females	14	21.4
Control		
Males	14	24.4
Females	14	22.6

* = Significant difference.

Although sex of subject was the only significant effect found in this study, the actual relationship was weak. In the matched-group analysis, calculation of a strength of association measure (ω^2) indicated sex of subject accounted for 8% of the variance in spatial visualization scores. In effect, 92% of the variance in spatial visualization performance was determined by other factors. Other measures (Pearson's coefficient of determination) used on the data of all 99 subjects participating in this study indicated that sex of subject accounted for 16% of the variance in spatial scores while IQ scores accounted for 18% of the variance.

The amount of variability that is not controlled in a study strongly affects the amount of variance accounted for by the independent variable and from one study to the next the amount of variance accounted for by the same independent variable can also vary depending on the amount of care exercised in controlling all extraneous variables (Linton and Gallo 1975). Since it was intended to exercise extreme care in the control of variables, a survey of the literature was made to compare the type of control exercised in similar studies and if possible, to determine the amount of variance accounted for by sex in spatial performance in those studies. Twelve studies were found that investigated some aspect of spatial performance, sex-related differences and other factors. In addition, a review article (Allen and Cholet 1978) was found that reported strength of association between sex and field dependence from 38 studies using either the Rod and Frame Test or Embedded Figures Test. Since spatial visualization factor has been implicated as the major factor contributing to findings of sex-related differences in these tests, the results of this survey seemed relevant. Allen and Cholet (1978) calculated median ω^2 values based on 20 Rod and Frame results (ω^2=.11) and 18

Embedded Figure results (ω^2=.12) and concluded that sex of subject accounted for less than 15% of the variance in field dependence scores. Of the other twelve studies surveyed, none reported strength of association measures between sex of subject and spatial performance, although all reported sex as a significant effect. Nor was sufficient information reported in summary tables to allow calculation of such measures. Only two of the twelve studies (Fennema and Sherman 1977; Hyde, Geiringer and Yen 1975) collected information on other variables beyond sex, SES, handedness and years of schooling or training. None of the ten studies made any attempt to control for the variables mentioned above, rather mean scores were simply reported for each variable. Hyde et al. (1975) reported data on seven variables and used correlational techniques to remove the variance accounted for by verbal ability and spatial ability from mathematic scores to reduce sex-related differences in mathematic performance. Fennema and Sherman (1977) collected information on fourteen variables and in addition to other techniques, matched subjects. They found small sex-related differences in spatial performance in only two of four high school populations. They concluded that sociocultural factors were highly important concomitants of sex-related differences in both mathematic achievement and spatial visualization performance. They pointed to the fact that the two populations with significant sex-related differences in cognitive performance also demonstrated the highest number of sex-related differences in affective factors, six out of eight.

Although none of the studies surveyed reported strength of association estimates concerning sex and spatial performance, the estimate of the strength of the relationship between sex and spatial visualization calculated in this study is believed to be a valid and replicable estimate. The results of this study fit with the range of estimates calculated by Allen and Cholet (1978) and in contrast to the studies surveyed, a greater effort was exerted to control other variables relating to sex.

While only two variables (sex of subject and IQ score) were found to correlate moderately with spatial scores in the correlational analysis of 99 subjects, several variables associated with sex-role and sex bias did show low to moderate correlations ranging from r=-.21 to r=.34 (see Table 8, p.67). The direction of the relationship was toward the male sex-role stereotype for the variables of parental identification, M-F scale and achievement motivation while high scores on the F scale showed a negative relationship with high spatial scores. These results tend to reflect the findings of Fennema and Sherman (1977) and suggest a sociocultural influence. Sex-role attitudes toward spatial skills may be an important factor to investigate. This has been demonstrated by other studies relating cognitive abilities and sex-role attitudes (Dwyer 1974, Paulsen and Johnson 1983; Stein and Smithells 1969).

Another factor, problem-solving strategies, was not considered in this study due to the length of the battery of tests. Several investigators have found sex-related differences in problem solving strategies (Allen 1974; Allen and Hogeland 1978; McGee 1978b). All three studies reported females used the same strategies as males in solving spatial problems, but they used those strategies less often, less efficiently and tended to resort to more guessing and concrete solution styles. This seems a promising area of research.

The second part of study one dealt with the expectation that mathematic problem solving skills were strongly related to spatial skills. It had been predicted that gymnasts by virtue of their training would excel in both spatial and mathematic performance. Sex-related differences in mathematic performance were only expected in the control group. However, no differences were found in mathematic performance by category or by sex in the study one group and when the analysis was expanded to include all subjects in both study one and two, no sex-related differences were found by category or by sex. This finding raises some question about the relationship of mathematic and spatial performance. Moderate correlations were found between spatial and mathematic performance in the third part of the study while significant differences favoring males in spatial performance were found across all subjects. Given these findings, the finding of no sex-related differences in mathematic performance is somewhat surprising. However, similar results have been obtained elsewhere. Fennema and Sherman (1977) found sex-related differences in spatial performance and in mathematic achievement in two out of four high school populations but only one population in which both occurred (see Table 12). Of most interest was the pattern of differences in mathematic achievement, spatial visualization, attitude scores and socioeconomic class. As previously reported, Fennema and Sherman concluded that sociocultural factors were the most important factors in mathematic achievement.

Table 12. F Ratios for Sex in Four High Schools.

TEST	SOURCE	1	2	3	4
Mathematics	sex	8.73**	3.80	1.44	27.26**
Spatial	sex	.98	4.64*	.56	14.27**

* = p .05
** = p .01

Adapted from Fennema and Sherman (1977).

Subjects in this study obtained similar scores on most sociocultural variables, with the exception of sports involvement and mathematic background. Since the subjects in this study were very similar in many aspects, it may be that this was sufficient to overcome differences in mathematic background that, while statistically significant, practically, were not that substantial (i.e., approximately 1.7 courses).

Study Two

The hypothesis spatial skills can be learned and improved through training and practice was confirmed, but the hypothesis predicting a female differential response to training was not confirmed.

Sex-related differences favoring males still remained following training. The design of this portion of the study was based on an investigative model (norm of reaction) used by Goldstein and Chance (1965) and McGee (1978b) to test the Sherman Hypothesis. The model rests on two assumptions. One, the asymptotic level of spatial visualization skills does not differ between the sexes and two, males have more relevant spatial experiences than do females. If these assumptions are correct, females would be expected to show a greater rate of improvement than males because females begin the task at a lower level. Goldstein and Chance (1965) demonstrated this effect with practice on an extended series of 68 embedded figures. The initial significant sex-related mean difference in discovery time was reduced almost to zero by the final trials. All subjects showed significant improvement with practice.

McGee (1978b) used the same model to test the effects of training on the SMMR test. The methods used varied somewhat from the previous study in that subjects were exposed only to a single training session following the first testing session. Pretesting and post-testing sessions were spaced three weeks apart. McGee found all subjects demonstrated a significant improvement in spatial scores across training but the initial significant sex-related difference in spatial scores remained at post-testing. Females did not show a greater rate of improvement.

Since the two studies appeared to be at opposite ends of a training continuum, task specific versus an hour lecture on spatial ability, this study attempted to investigate training conditions that fell near the midmark of training. Architectural training was selected since it does not train to a specific task but does train intensively in spatial relations. The results of this study were very similar to those of the McGee (1978b) study. Significant sex-related differences were found in both pretraining and post-training conditions. However, both sexes showed a statistically significant gain in scores at the end of training. Males averaged a mean improvement of 5.4 points and females gained an average of 6.4 points. The difference between male and female gains was not significant and too small to call a trend. The mean score for males at the end of training was 35.8 out of a possible score of 40 and females did not quite reach the male pretest score of 30.4

It would be easy to conclude from these results that the asymptotic level of spatial visualization skill does vary in the two sexes. It would be erroneous to conclude that these findings have proven environmental factors to be of less importance in influencing the usual path of development of spatial skills than genetic factors (Harris 1978). As Wittig (1979) noted, "Genes predispose a range of outcomes and rarely mandate any particular outcome... Mechanisms may be involved which allow both usual and unusual paths of development."

While no conclusions regarding the effects of early physical training on the development of spatial skills, can be drawn from the results of study one, males clearly differed from females in the level of involvement in physical activities. Socio-cultural values also seemed to be involved and sex of subject accounted for only a small portion of the variance ir spatial scores. A complex interaction based on biological sex and differential socio-cultural response to biological sex remains as a reasonable explanation.

The results of this study and others (Goldstein and Chance, 1963; McGee, 1978b) indicate that perceptual learning can indeed occur in later stages of development. However, none of these studies have effectively defined the limits of perceptual learning. The important and difficult question to be addressed is, "How does perceptual learning occur and what are the best methods to train perceptual skills?" Each of these studies, including the present research, have addressed a narrow area, yet each has contributed information that should be useful in defining future research questions. What can be concluded from the results of these studies is perceptual learning has been demonstrated using two different spatial tasks, set breaking and spatial visualization, in several college populations. In these populations, task specific training appears to be more effective than general training. However, an investigation of the effectiveness of task specific versus general training has not been tried on spatial visualization tasks. Additionally, it is not known whether task specific training will generalize. In this study, generalized training did promote significant improvement in skills on an extremely difficult spatial task. It would be interesting in future investigations to expand the model used in this study to include several measures of spatial visualization and different modes of training across a range of age groups. It would also be important to sample mathematic performance at intervals to assess the effects of differential spatial training on the development of mathematic skills.

Study Three

Low to moderate correlations were found between scores on the SMMR test, the 17-item Otis mathematic test and the two college entrance quantitative scores. The correlation between spatial scores and the Otis mathematic scores was .49 for Study One subjects and .33 for the total population (N=166). The correlations between spatial scores, the ACT and the SAT were .38 and .49, respectively. These results were very similar to those produced by the Hyde et al. (1975) study which obtained correlation coefficients of .49 between spatial scores and mental arithematic scores. Correlations obtained by sex differed from usual findings (i.e., Fennema and Sherman 1977; Hyde et al. 1975; Werdelin 1961) as females obtained higher correlation between mathematic and spatial scores (.30) than did males (.20). Typically higher correlations are found for males.

The results of this study support the findings of the most recent correlational studies in establishing a moderate association between spatial and mathematic performance. However, correlation does not imply causation and the results of this investigation do not appear to supply any support for the theoy that sex-related differences in spatial performance are the basis of sex-related differences in mathematic performance. While sex-related differences were found in spatial visualization performance, the expected differences in mathematic performance did not occur. Sociocultural factors may be important, although results in this area were weak in this investigation. However, it was not intended to directly investigate or test these factors in this study, rather the intention was to control sociocultural factors. Although Fennema and Sherman (1977) continued to maintain that spatial visualization was a factor contributing to sex-related differences, the results of their study were very similar to this study in finding sex-related differences in spatial performance not always associated with sex-related differences in mathematics. Sex-related differences in both spatial visualization and mathematics occurred in only one of their four populations. Sex-related differences in spatial performance were found in a second group, but they were not associated with sex-related differences in mathematics. A third group demonstrated sex-related differences in mathematics but not in spatial performance (see Table 12, p.81). Patterns of differences in spatial visualization scores, mathematic achievement, response to affective scales and socioeconomic class pointed to sociocultural factors having a strong influence on cognitive performance.

Correlations obtained by sex in this study indicated that the relationship between spatial visualization and mathematic performance was somewhat stronger for females than males. This is an unusual finding and difficult to explain. While it might be due in part to the choice of instruments used to measure spatial and mathematic performance, sociocultural factors might also be implicated. The females in this population could be a highly selected group as generally they tended to come from the higher socioeconomic classes. The females in this study may also be reflecting the changes in societal values towards the female role that have occurred in the past decade or so. For example, females are encouraged to select from a broader range of career choices, are allowed greater involvement in physical activities and sports and are permitted to act more aggressively and competitively. The females in this population certainly tended to identify more with the androgenous role than the traditional feminine role and scored as high as males on the achievement motivation scale. This is an area that requires further thought and investigation.

Summary

The intention of this investigation was threefold. One goal was to examine the influence of early physical training on the development of abstract perceptual and cognitive functions (spatial visualization and mathematic performance). Another goal was to determine whether short term intensive training would have a differential impact on male/female spatial visualization performance. A major goal was to gather information relating spatial visualization and mathematic performance and to assess the strength of that relationship if found.

As typically happens, this investigation has had both success and failure. The question relating to the influence of early physical training on the development of abstract perceptual and cognitive functions remains unanswered because the target group did not really meet the criteria of training during childhood. The second question concerning differential response to training, while answered in some respects, requires further investigation. Both males and females significantly improved spatial visualization performance after training but females did not show a greater rate of improvement than males. The results of this study indicated that a moderate relationship between spatial visualization and mathematic performance does exist and correlation coefficients fell within the range of those found in previous studies. However, no evidence was found to indicate that spatial skill contributed to mathematic performance as sex-related differences were found in spatial visualization performance but not in mathematic performance. This is an important question for future investigation as there has been a tendency to attribute sex-related differences in mathematic performance to differences in spatial skills without basis in fact. Finally, it was found that only 8% to 18% of the variance in spatial visualization scores could be accounted by the variable sex-of-subject. Sociocultural factors relating to sex-role may be more important in both areas and this too is a subject that needs further investigation.

APPENDIX A

DEMOGRAPHIC TABLES

Table A-1. Ethnic Group, Absolute and Relative Frequencies by Category, Sex for Total Population in Study One.

CATEGORY	n	Cauc.	Black	Hisp.	Asian	Am-Ind.	Other	Data missing
Gymnast								
Males	15	11 73.3%	0 0%	2 13.3%	0 0%	0 0%	1 6.7%	1 6.7%
Females	25	20 80.0%	0 0%	2 8.0%	3 12.0%	0 0%	0 0%	0 0%
Control								
Males	24	16 66.7%	4 16.7%	1 4.2%	1 4.2%	0 0%	0 0%	2 8.3%
Females	35	27 77.1%	2 5.7%	1 2.9%	1 2.9%	1 2.9%	1 2.9%	2 5.7%

Table A-2. Socioeconomic Status, Absolute and Relative Frequencies by Category, Sex for Total Population in Study One.

CATEGORY	n	1	2	3	4	5	Data missing
Gymnast							
Males	15	2 13.3%	4 26.7%	2 13.3%	3 20.0%	0 0%	4 26.7%
Females	25	10 40.0%	5 20.0%	9 36.0%	1 4.0%	0 0%	0 0%
Control							
Males	24	2 8.3%	5 20.8%	5 20.8%	5 20.8%	3 12.5%	4 16.7%
Females	35	7 20.0%	6 17.1%	7 20.0%	8 22.9%	7 20.0%	0 0%

Table A-3. Sex-Role Identification, Absolute and Relative Frequencies by Category, Sex for Total Population.

CATEGORY	n	Masculine	Feminine	Androgenous	Undifferentiated	Data missing
Gymnast						
Males	15	6 40.0%	0 0%	5 33.3%	3 20.0%	1 6.7%
Females	25	4 16.0%	5 20.0%	14 56.0%	2 8.0%	0 0%
Control						
Males	24	11 45.8%	2 8.3%	5 20.8%	6 25.0%	0 0%
Females	35	4 11.4%	7 20.0%	16 45.7%	8 22.9%	0 0%

Table A-4. Parental Identification, Absolute and relative Frequencies by Category, Sex for Total Population in Study One.

CATEGORY	n	Father	Mother	Both Equally	No Identification	Data Missing
Gymnast						
Males	15	5 33.3%	2 13.3%	5 33.3%	0 0%	3 20.0%
Females	25	2 8.0%	13 52.0%	7 28.0%	0 0%	3 12.0%
Control						
Males	24	6 25.0%	11 45.8%	3 12.5%	0 0%	4 16.7%
Females	35	9 25.7%	11 31.4%	11 31.4%	2 5.7%	2 5.7%

Table A-5. Study One Matched-Groups: Ethnic Group, Absolute and Relative Frequencies by Category, Sex.

CATEGORY	CAUC.	BLACK	HISP.	ASIAN	AM-IND	OTHER	DATA MISSING
Gymnast							
Males	11 78.6%	0 0%	1 7.1%	0 0%	0 0%	1 7.1%	1 7.1%
Females	11 78.6%	0 0%	1 7.1%	2 14.3%	0 0%	0 0%	0 0%
Combined Mean	22 78.6%	0 0%	2 7.1%	2 7.1%	0 0%	1 3.6%	1 3.6%
Control							
Males	8 57.1%	2 14.3%	1 7.1%	1 7.1%	0 0%	0 0%	2 14.3%
Females	11 78.6%	1 7.1%	0 0%	1 7.1%	0 0%	0 0%	1 7.1%
Combined Mean	19 67.9%	3 10.7%	1 3.6%	2 7.1%	0 0%	0 0%	3 10.7%

n = 14
N = 56

Table A-6. Study One Matched-Groups: Socioeconomic Status, Absolute and Relative Frequencies by Category, Sex.

CATEGORY	1	2	3	4	5	Data Missing
Gymnast						
Males	2 14.3%	4 28.6%	1 7.1%	3 21.4%	0 0%	4 28.6%
Females	8 57.1%	3 21.4%	3 21.4%	0 0%	0 0%	0 0%
Combined Totals by %	10 35.7%	7 25.0%	4 14.3%	3 10.7%	0 0%	4 14.3%
Control						
Males	2 14.3%	3 21.4%	4 28.6%	1 7.1%	2 14.3%	2 14.3%
Females	5 35.7%	3 21.4%	1 7.1%	3 21.4%	2 14.3%	0 0%
Combined Totals by %	7 25.0%	6 21.4%	5 17.9%	4 14.3%	4 14.3%	2 7.1%

n = 14
N = 56

Table A-7. Study One Matched-Groups: Sex-Role Identification: Absolute and Relative Frequencies by Category, Sex.

CATEGORY	Masculine	Feminine	Androgenous	Undifferentiated
Gymnast				
Males	6 42.9%	0 0%	5 35.7%	3 21.4%
Females	3 21.4%	3 21.4%	8 57.1%	0 0%
Combined Total	9 32.1%	3 10.7%	13 46.5%	3 10.7%
Control				
Males	4 28.6%	2 14.3%	4 28.6%	4 28.6%
Females	2 14.3%	3 21.4%	5 35.7%	4 28.6%
Combined Total	6 21.4%	5 17.9%	9 32.1%	8 28.6%

n = 14
N = 56

Table A-8. Study One Matched-Groups: Parental Identification, Absolute and Relative Frequencies by Category, Sex.

CATEGORY	Father	Mother	Both Equally	None	Data Missing
Gymnast					
Males	5 35.7%	2 14.3%	5 35.7%	0 0%	2 14.3%
Females	0 0%	10 71.4%	3 21.4%	0 0%	1 7.1%
Combined Totals	5 17.9%	12 42.8%	8 28.6%	0 0%	3 10.7%
Control					
Males	2 14.3%	9 64.3%	1 7.1%	0 0%	2 14.3%
Females	3 21.4%	6 42.9%	4 28.6%	1 7.1%	0 0%
Combined Totals	5 17.9%	15 53.5%	5 17.9%	1 3.6%	2 7.1%

n = 14
N = 56

Table A-9. Study One Matched Groups: Mean Scores and Standard Deviation by Sex on Selected Matching Variables.

Sex	n		IQ Score	Mathematic* Background	Sports Training	Sports* Involvement	Achievement Motivation
Males	28	21.5 ±3.1	114.8 ±10.3	5.8 ±1.8	10.6 ±12.6	19.5 ±21.3	63.6 ±8.3
Females	28	20.6 ±3.1	114.3 ±10.6	4.2 ±1.5	8.8 ±9.5	7.4 ±9.7	64.6 ±8.5

* = significantly different.

Table A-10. Study One Matched Groups: Ethnic Group, Absolute and Relative Frequencies by Sex.

Sex	Cauc.	Black	Hisp.	Asian	Am-Ind	Other	Data Missing
Males	19 67.9%	2 7.1%	2 7.1%	1 3.6%	0 0%	1 3.6%	3 10.7%
Females	22 78.6%	1 3.6%	1 3.6%	3 10.7%	0 0%	0 0%	1 3.6%

Table A-11. Study One Matched-Groups: Socioeconomic Status, Absolute and Relative Frequencies by Sex.

Sex	1	2	3	4	5	Data Missing
Males	4 14.3%	7 25.0%	5 17.9%	4 14.3%	2 7.1%	6 21.4%
Females	13 46.4%	6 21.4%	4 14.3%	3 10.7%	2 7.1%	0 0%

n = 28
N = 56

Table A-12. Study One Matched-Groups: Sex-Role Identification, Absolute and Relative Frequencies by Sex.

Sex	Masculine	Feminine	Androgenous	Undifferentiated
Males	10 35.7%	2 7.1%	9 32.1%	7 25.0%
Females	5 17.9%	6 21.4%	13 46.3%	4 14.3%

n = 28
N = 56

Table A-13. Study One Matched-Groups: Parental Identification: Absolute and Relative Frequencies by Sex.

Sex	Father	Mother	Both Equally	None	Data Missing
Males	7 25.0%	11 39.3%	6 21.4%	0 0%	4 14.3%
Females	3 10.7%	16 57.1%	7 25.0%	1 3.6%	1 3.1%

n = 28
N = 56

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