CHAPTER-II

REVIEW OF RELATED LITERATURE

The study of related literature is of a great importance to research problems and it helps to make progress towards the solution and successful completion of the research project. The study of athletes has been of interest to researchers in a variety of disciplines. Biologists, anthropologists, physiologists, sociologists and sports scientists have investigated the high level performers from various viewpoints. Modern sports rely on science in order to enhance performance, maintain safety and ensure long term health. Women's gymnastics in particular has been sought and continues to need scientific assistance, because children in gymnastics are involved relatively at a very young age to high level of performance and competition.

Studies regarding the structural, morphological and physiological characteristics of champion athletes have been conducted since the beginning of 20th century (Sargent, 1887; Bemies, 1900; Amar, 1920; Mohr and Gundlash; 1927, Cozens, 1930 and Arnold, 1931).

Female athletes have been reported by de Garary et al, 1974; Novak et al, 1977; Carter et al, 1979; Ross et al, 1981;

No study directly connected to the present study could be traced out in the literature available, however some works allied to the present study has been done previously. It is also important to hint an understanding of relevant and connected literature to get a full picture of what has been said with regard to the problem taken up for the study. A review of the available literature directly or indirectly related to the present study is presented in the following three headings:

- **Studies related to Morphological Characteristics**
- **Studies related to Cardiovascular Fitness**
- **Studies related to Motor Abilities**

### 2.1 Studies Related to Morphological Characteristics of Athletes:

Morphological profile of an individual is determined in terms of size and shape. Various researchers have investigated the structural and morphological aspects of body in relation to the type of activity (Digiovanna, 1943; Medred, 1966; Sodhi, 1976; Slaughter et al, 1980; Grewal, 1983 and Steven, 1983). In the recent past attempts has been made by Franco and Fabio,
1993; Monsma and Malina, 2005; Cristobal et al, 2007 and Malousarins et al, 2008 to understand the specific body composition which helps them to attain better performance.

Some authors have suggested a secular trend towards increasing size in some events (Kunze et al, 1976). Asmussen (1966) noted that although champion athletes have increased in body size since 1927, their body proportions have remained remarkably constant. While studying the Montreal Olympic athletes, Hirata (1979) also observed that height gradually increased between the 1964 and 1976 Olympics for those sports where height is an important factor, athletes became taller, whereas, for sports where height is not so important (e.g. long distance runners, cyclists), no changes were observed.

Kohlrausch (1929) was the first to have reported the findings of measurements of Olympic athletes. He measured approximately 300 athletes who participated in 1928 Olympic Games at Amsterdam. It was the first adequate data on the body size of the Olympic athletes in different sports. Mean values were presented for track and field athletes, boxers, wrestlers, weight lifters etc. He concluded that there were differences in body dimensions between events. Tanner (1964) examined the
physique and body composition of Olympic athletes, and found that the athletes were both, born and made.

**Medred (1966)** surveyed the 596 adult sports women (over the age of 17 years) and equal number of controls of the same age group and concluded that female athletes in track and field events and in rowing events were considerably taller at 1% level of significance, the table tennis player were found to be taller at 5% level of significance.

The most extensive study so far is that of **de Garay et al (1974)** who examined 1265 athletes (1117 males and 148 females) who participated in 13 sports at the Mexico Olympics in 1968. It was concluded that there were significant differences in the body size and somatotypes of participants among events in some sports but there were few or no differences among events in other sports. Data on age, height, weight and ponderal index of 711 female Montreal Olympic athletes (Basketball=81, Volleyball = 104, Handball = 81, and athletes = 445) were reported by **Hirata (1979)**. He revealed that the Basketball players and the high jumpers were the tallest among all the other categories. **Hebbelinck et al (1980)** compared the Montreal Olympic female rowers with the non rowers. The
Olympic female rowers were found to be taller, heavier and larger in all 29 body measurements than the reference samples.

Thorland and Johnson (1981) examined body composition and somatotype characteristics of Junior Olympic athletes. The athletes studied were gymnasts, wrestlers, divers, track and field jumpers, throwers and middle distance runners. All categories of athletes were compared with each other and also with the reference non-athletes. Female gymnasts and divers were categorized together. The researchers found a significant difference between the somatotype of the gymnasts and divers compared to other athletes. Comparison of the female athletes and the reference female revealed that the Junior Olympic competitors, except gymnasts and divers, were considerably taller. In addition, gymnasts and divers were lighter than throwers in body weight. All competitors except for gymnasts and divers were notably higher in lean body weight than the reference female.

A study on size and somatotype correlations of strength and physiological performance in adult male students was conducted by Bale et al (1984). They investigated relationship between somatotype and performance and reported that those performed best in activities involving strength and power were in
the endo–mesomorphic group. The students with greater aerobic capacity in relation to their weight had balanced or more ectomorphic physiques.

Carter (1984) studied the somatotypes of Olympic athletes from 1948 to 1976 Olympic Games. 1757 male and 289 female Olympic athletes competing in 23 sports at four Olympic Games were analyzed. Athletes were found to be less endomorphic and more mesomorphic than reference group. The average somatotype for male athletes was 2-5-2.5 and for female athletes it was recorded as 3-4-3. Bale (1991) studied 17 basketball female players and noted their somatotype mean values as under:

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<th>Centres</th>
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<tr>
<td>Endomorphy</td>
<td>4.1</td>
<td>3.5</td>
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<tr>
<td>Mesomorphy</td>
<td>3.5</td>
<td>3.8</td>
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<tr>
<td>Ectomorphy</td>
<td>3.7</td>
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Franco and Fabio (1993) collected data on 50 amateur female volleyball players, and were measured according to the Heath Carter anthropometric somatotype method. They were divided in to junior (13-18 years old) and senior (above 18 years) groups. Their somatotype scales were found as 4.9-3.8-2.6 and
4.7-3.9-2.3 respectively. No significant differences emerged for any of the components of the somatotype between the two groups.

**Paramdeep and Sidhu (2003)** studied the somatotype components of All India inter university female throwers. Short putters were found to be taller than discus throwers and javelin throwers. Study also revealed that short putter possess maximum mean components of endomorphy (4.74) and mesomorphy (4.56) among throwers. The javelin throwers were found to have maximum mean ectomorphy (2.54) component than discus throwers (1.72) and short putters (1.47).

**Bayios et al (2006)** studied anthropometric profile, body composition and somatotype of elite Greek female basketball (B), volleyball (V) and handball (H) players to compare the mean scores among sports and to detect possible differences in relation to competition level. The results showed that volleyball athletes were the tallest (p<0.001) among the three groups of athletes, had the lowest values of body fat (P<0.001) and their somatotype was characterized as balanced endomorph (3.4-2.7-2.9). Basketball athletes were taller (p<0.01) and leaner (p<0.001) than handball players, with a somatotype characterized as mesomorph-endomorph (3.7-3.2-2.4).
Handball athletes were the shortest of all (p<0.01), had the highest percentage of body fat (p<0.001) and their somatotype was mesomorph-endomorph (4.2-4.7-1.8). In comparison with their A2 counterparts, the A1 division players were taller (P<0.001) and heavier (p<0.01), but at the same time leaner (p<0.001), and exhibited higher homogeneity in somatotype characteristics (p <0.05). It was concluded that anthropometric, body composition and somatotype variables of Greek female elite team ball players varied among sports.

Khanna and Indranil (2006) studied the morphological, physiological and biochemical characteristics of Indian senior and junior national level boxers, as well as, to assess the cardiovascular adaptation to graded exercise and actual boxing round. Results showed a significantly higher (p < 0.05) stature, body mass, LBM, body fat and strength of back and grip in senior boxers compared to juniors. Moreover, the senior boxers possessed mesomorphic body conformation whereas the juniors possessed ectomorphic body conformation. Significantly lower (p < 0.05) aerobic capacity and anaerobic power were noted in junior boxers compared to seniors. Further, significantly higher (p < 0.05) maximal heart rates and recovery heart rates were observed in the seniors as compared to the juniors. Significantly
higher maximum heart rates were noted during actual boxing compared to graded exercise.

**Bandyopadhyay (2007)** studied 50 sedentary males and 128 sportspersons (volleyball=82, soccer=46) of 20–24 years from West Bengal, India, to evaluate and compare their anthropometry and body composition. Skinfolds, girth measurements, body fat percentage (%fat), and endomorphy were noted significantly higher among sedentary individuals, but lean body mass (LBM) and mesomorphy were significantly (p<0.001) higher among the sportspersons. Soccer and volleyball players were found to be ectomorphic mesomorph, whereas sedentary subjects were endomorphic mesomorph. The soccer and volleyball players had higher %fat with lower body height and body mass than their overseas counterparts. The study exhibited a significant correlation between percent fat and body mass index (BMI).

**Cristobal et al (2007)** study the elite junior tennis players with the aim to describe the anthropometric characteristics, body composition and somatotype and to compare the first 12 elite junior tennis players on the ranking with the lower ranked players. No significant differences in height and weight were found between the first 12 and the lower ranked boys, while the
first 12 girls were significantly taller than the lower ranked girls (p = 0.009). Significant differences were found for humeral and femoral breadths between the first 12 and the lower ranked girls (p = 0.000; p = 0.004, respectively). The mean (SD) somatotype of elite male junior tennis players was defined as ectomesomorphic (2.4 (0.7), 5.2 (0.8), 2.9 (0.7)) and the mean and SD somatotype of elite female junior tennis players evaluated was defined as endomesomorphic (3.8 (0.9), 4.6 (1.0), 2.4 (1.0)). No significant differences were found in somatotype components between the first 12 and the lower ranked players of both genders.

Gabbett and Georgieff (2007) investigated the physiological and anthropometric characteristics of junior volleyball players competing at the elite, semi-elite, and novice levels to establish performance standards for the athletes. One hundred and fifty-three junior national (N = 14 males; N = 20 females), state (N = 16 males; N = 42 females), and novice (N = 27 males; N = 34 females) volleyball players participated in the study. Significant differences (p < 0.05) were detected among junior national, state, and novice volleyball players for height, standing reach height, skinfold thickness, lower-body muscular power, agility, and estimated maximal aerobic power and observed that the physiological and anthropometric
characteristics of players typically improving with increases in playing level.

**Malousaris et al (2008)** studied 163 elite female volleyball players (age: 23.8+/−4.7 years) to describe the morphological characteristics. For this purpose, body weight and height, breadths and girths as well as skinfold thickness at various body sites were assessed. Seventy-nine of these players were from the A1 division and the rest from the A2 division of the Greek National League. The volleyball players of the study were mainly balanced endomorphs (3.4−2.7−2.9). The A1 division players were taller and slightly leaner with greater fat-free mass than their A2 counterparts. Significant differences were found among athletes of different playing positions which have been interpreted by their varying roles and physical demands during a volleyball game.

**Pritam et al (2008)** investigated the 120 inter-university throwers and long distance runners to find out the somatotype characteristics. The throwers were found heavier and taller as compared to long distance runners. The endomorphy and mesomorphy components were noticed maximum in throwers (shout putters followed by discus and javelin throwers) followed by runners (5000 metre followed by 10,000 metre and
cross country runners). The study also discovered that Inter-university athletes were more endomorphic and less mesomorphic as compared to the elite Indian athletes and Olympic level athletes.

A study by Brajnath and Sangita (2009) was conducted to find out the comparative assessment of somatotype and body composition variables between north-zone and east-zone university level women basketball players (N=142). The results revealed that the somatotype of both north-east zone women player was mesomorphic - endomorph except the champion University. The physique of champion team (GNDU) were ectomorphic -endomorph. It was also found that North-Zone women basketball players possessed less % fat, less weight of body fat, higher LBM and were taller and heavier than the east-zone players.

Chauhan and Ramchander (2009) computed data on 40 college level volleyball players between the age ranges of 18 to 24 years. The study found significant correlation of height, weight, sitting height, leg length, and foot length with explosive leg strength of volleyball players. Body composition variables (i.e. percent body fat and lean body mass) were found to be significantly correlated with explosive leg strength.
**Gopinathan and Helina (2009)** conducted study on 45 male handball players to assess the correlation of anthropometric and physical fitness variables to handball performance. The results revealed that height, weight, arm length, leg length, palm span and sum of four skin folds, speed, agility, explosive power, shoulder strength, strength endurance were having significant relationship with handball performance.

**Harmanpreet et al (2009)** conducted study on 120 female hockey players (state and national level) and 60 controls in the age group of 18-25 years. The findings of the study showed that hockey players of both levels were significantly taller and lighter than the control group. The national level hockey players were having significantly greater bone mass (t = 4.30) and lesser percent body fat (t = 5.44) than state level players.

**Ranawat and Kang (2010)** conducted study on Indian 20 Km walk event probables for 2010 Commonwealth Games. The morphological characteristics of the male walkers were found to be closer to the desirable values of their Olympic counterparts. However, female walkers were not found to possess the desirable morphological characteristics as those of their Olympic counterparts.
Suresh et al (2010) computed data on Manipur marathon runners and found the mean values of percent fat (15%), far behind to their international counterparts.

### 2.2 Studies Related to Morphological Characteristics of Gymnasts:

The face of gymnastics has changed. Until the 1970's, the gymnastics world was dominated by women who emphasized the grace and artistry of gymnastic performance. Today female gymnasts are lighter, shorter and more ectomorphic than earlier gymnasts. This type of physique is well suited to the biomechanical demands of a more acrobatic performance (Bale, 1994; Calabrese, 1985 and Vercruyssen and Lorraine, 1998).

Medred (1966) while studying the adult female gymnasts concluded that the height of the adult female gymnasts was less (160.54 cm) than the average group (161.9 cm). Pool et al (1969) took anthropological and physiological measurements on 38 female gymnasts who participated in European Championship in 1967 held at Amsterdam. The gymnasts were characterized by small height (Mean=158cm) and weight (Mean=52.6 kg). The female gymnasts were found extraordinary smaller on their skinfolds, which were found to be correlated negatively with their performance. Muscles were found to be well
developed and correlated significantly with the total score. The running time and jump height of the gymnasts also found to be correlated significantly with the marks for floor exercises.

Body dimensions of six Japanese and seven American male gymnasts were studied by LeVeau et al. (1974). Comparison of the two groups revealed distinct differences. The Japanese gymnasts were found to be shorter (164.3 cm) than American gymnasts (169.6 cm.) but similar in body weight (61.8 kg, 61.4 kg) respectively. The Japanese gymnasts were also found to be shorter in shanks, arm, hands and feet when compared with the American gymnasts. The study concluded that Japanese differ significantly from American in certain body proportions which provide them a biomechanical advantage for performance in most gymnastic events. As a group the gymnasts were different from most other athletes.

Falls and Humphery (1978) collected data on 71 female gymnasts and 54 non-athletes (NA). The gymnasts were divided into two groups i.e. placers (P) included those gymnasts who got position in the competition and non-placers (NP) included those gymnasts who did not get any position in the competition. It was concluded that placers were shorter and lighter (161.5 cm, 55.1 kg) than NP = (162.1 cm, 55.2 kg) and than the non athletes
(164.6 cm, 58.5 kg), with significantly less amount of body fat (P = 16.82%, NP = 18.4%, NA = 21.45%) respectively. While comparing the placers and non-placers among themselves it was observed that both the groups were almost identical in height and weight.

**Bale (1981)** found the mean somatotype characteristics of the gymnasts (3.5 - 3.9 - 2.9) as compared to hockey players (3.5 - 4.1 - 2.6), basketball players (3.7 - 3.4 - 3.3), swimmers (3.6 - 4.0 - 2.7) and cross country athletes (2.8 - 3.0 - 4.8). **Beunen et al (1981)** reported data on 23 Blegium female gymnasts and 450 control subjects of the same age group. The mean age was recorded 16.6 years. It was concluded from the study that the gymnasts had smaller body dimensions than the reference group except for biacromial width and upper arm circumference. Relative to their height, the gymnasts possessed shorter trunks and a relatively larger muscle mass. It was also concluded that the female gymnasts were smaller in their hips relative in their biacromial width than the controls. The mean somatotype of female gymnasts was recorded as 2.4 - 3.7- 3.1.

**Carter (1984)** recorded the somatotype characteristics of female gymnasts of two Olympic Games as follows:
Shankar (1985) investigated the 13 position winner (PW) and 28 non-position winner (NPW) female gymnasts. The mean age of PW was 17.5 years and NPW was 17.4 years. No significant differences were found in height (PW= 58.6, NPW= 60.1) and weight (PW=90.7 lbs, NPW = 89 lbs) between position winners and non-position winners, but the former were found to be significantly more endomorphic and mesomorphic and less ectomorphic than the latter.

Broekheff et al (1986) collected data on eighteen female (X= 13.32 years) young American gymnasts. The female gymnasts were noted to be significantly shorter and lighter (X =150.21 cm, 42.0 kg) than controls (X =160.46 cm, 50.88 kg). It was also concluded that in proportion to the body height, the female gymnasts had significantly larger upper arm girth, humerus width; broader shoulders and narrower hips than the reference group.

Claessens et al (1991) took anthropometric measurements of outstanding male and female gymnasts from

<table>
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<tr>
<th>Mexico Olympic Games 1968</th>
<th>N= 21</th>
<th>Mean= 2.7 - 4.2 - 2.8</th>
<th>S.D.= 0.7 - 0.5 - 0.5</th>
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<td>Montreal Olympic Games 1976</td>
<td>N =15</td>
<td>Mean =2.1- 4.0 - 3.4</td>
<td>S.D.= 0.4 - 0.6 - 0.7</td>
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the 1987 World Championship. Two hundred and one elite female gymnasts were measured for body dimensions and somatotype rating. The results were compared with reference data obtained at international gymnastics competitions of previous years. They found female gymnasts to be significantly (p< .01) smaller than gymnasts of previous years in weight and in all length dimensions including height. A decline in mean height from 159 cm to 154.3 cm was noticed and seemed to be accentuated between the 1976 Olympics and the World Championships at Budapest in 1983. Along with the height decline, there was a weight reduction from 52 kg to 45 kg. The skinfold measurement showed the 1987 gymnasts were thinner with 48% of the gymnasts showing an extremely low amount of subcutaneous fat. Not only did these physiological factors differ, but the gymnasts in 1987 were younger than all previous gymnasts with a decline in mean age from 22.7 in 1964 to 16.5 years of age in 1987. The researchers also found that there was more change in the shape of the female gymnast from 1967 to 1987 than that of the male gymnast.

Gualdi et al (1992) studied the skinfold and body composition of female gymnasts (N= 227, Mean age=19.6 Years) and were reported to have 19.59% of body fat and 43.92 fat free mass.
A study of contribution of anthropometric characteristics to performance score in elite female gymnasts was conducted by Claessens et al (1999). 168 female gymnasts (mean age: 16.5 +/- 1.84 years) who participated in 24th World Championship in 1987 were investigated. Competition scores for the four individual gymnastic events (vaulting table, uneven bars, balancing beam and floor exercises) and a composite score for each gymnast were the dependent variables. The results indicated the moderately high significant correlations (p < 0.01) (r = -0.38) between biceps skinfold and score on balance beam and (r= -0.60) between endomorphy and total score. It was observed that there is relatively strong relationship between several anthropometric variables and gymnastic performance in elite female gymnasts. It was also concluded that gymnasts with more subcutaneous fat and higher endomorphy have lower performance score.

Filaire and Lac (2002) examine the body composition, dietary intake and energy expenditure in 12 young female elite gymnasts aged 10.1 to 10.3 years. The female gymnasts were found to be shorter and had lower body weight compared with controls (p < 0.05). Percent body fat was significantly lower in gymnasts verses controls (p < 0.01). They also found gymnasts
with higher percentage of fat free mass (p < 0001) than the reference group.

**Timothy et al (2003)** conducted longitudinal study to measure the effect of body size on rotational performance in women’s gymnastics. Data were collected on 37 aged between 10-12 years female gymnasts. The results revealed that the smaller gymnast, with a high strength to mass ratio, has greater potential for performing skills involving whole-body rotations. Larger gymnasts, while able to produce more power and greater angular momentum, could not match the performance of smaller ones.

A studied on the physique, body composition and somatotype of female national gymnasts, swimming and track sprinters was conducted by **Kalpana and Bawa (2004)**. Gymnasts were found to be younger in age, lighter in weight, smaller in height, having lesser leg length, greater humerus bicondylar diameter, lesser femur bicondylar diameter and lesser thigh skinfold when compared with track and field sprinters.

**Elizabeth and Francisco (2006)** computed data to study the morphological assessment in elite Argentineans male gymnasts. The sample included 25 gymnasts, older than 18 years and divided them into two categories i.e. junior and senior. The study pointed out the Argentineans gymnasts were
composed by 54% of muscle mass and 17.5 % of fat mass. The results also showed the Argentinean gymnasts were having similar biotype characteristics to other international elite gymnasts.

A study to evaluate variation in the size and proportions of 150 elite female gymnasts has been conducted by Claessens et al (2006). The gymnasts were divided into three maturity groups i.e. from 14 to 17 years: Pre-menarcheal (N = 65); post-menarcheal but not skeletally mature (N = 37); post-menarcheal, skeletally mature (N = 48). The results showed that pre-menarcheal gymnasts were smaller in all dimensions compared to post-menarcheal gymnasts in all age groups. Post-menarcheal, skeletally mature gymnasts were heavier than pre-menarcheal gymnasts, but weight does not differ between gymnasts in the two post-menarcheal groups.

Nine artistic and thirteen rhythmic female gymnasts were studied by Vicente et al (2007) with 13 non-physically active controls. Study was conducted to know the effect of gymnastics on bone and muscle mass. The artistic gymnasts showed a delay in pubertal development compared to the other groups (p < 0.05). The artistic gymnasts had a 16 and 17% higher aerobic power and anaerobic capacity, while the rhythmic group had a
14% higher anaerobic capacity than the controls, respectively (p < 0.05). The artistic gymnasts had higher lean mass (p < 0.05) in the whole body and the extremities than both the rhythmic gymnasts and the controls.

**Irurtia et al (2009)** assessed the somatotype and body composition in elite Spanish gymnasts from childhood to adulthood. The results of the study indicated the male gymnasts to be significantly shorter and lighter than the reference population. The best gymnasts were even more so with respect to their fellow gymnasts, except for specialists in vault and floor where the lower limbs are especially important. The peak height velocity occurred at the age of 14, at the same age as in the reference population. The somatotype was ecto-mesomorphic in 90% of the gymnasts. Fat mass percentage was significantly lower in gymnasts than in the reference population. Somatotype, fat free mass and muscle mass showed no significant increases with age.

**Theophanis et al (2009)** studied the anthropometric characteristics of male and female gymnasts (N = 20), swimmers (N = 20) and equal number of non-athletes in the age group of 10-12 years. Triceps and calf skinfold thickness was used to estimate the body fat percentage and lean body mass percentage.
The results showed that male and female gymnasts had smaller body dimensions in some anthropometric characteristics compared to swimmers and non athletes, however, gymnasts were found having a higher percentage lean body mass and lean body mass / body fat ratio.

**Bester and Coetzee (2010)** studied the South-African female gymnasts (N = 12) to determine the contribution of anthropometric variables to the performance in vault item. Twelve young female gymnasts (Mean age =13.39 ± 2.14 years) were selected for the study and sixty one anthropometric variables were measured on the dominant side of the body. The successful gymnasts were significantly better on relaxed and flexed upper arm, ankle circumferences, as well as, having higher mesomorphi values than the less successful gymnasts. The findings concluded that larger upper arm and upper body circumferences; hand, foot, upper leg, triceps skinfold, fat percentage as well as a higher ectomorphy value are important anthropometric variables for vaulting performance.

From the above literature, the elite female gymnast have been found to have a balanced mesoectomorphic physique with a slim body, low in fat, small hips with relatively shorter trunks and quite broad shoulder. The gymnasts of today are shorter,
lighter and have a lower percentage of body fat than gymnasts from the past and athletes from other disciplines. It has also been found that the age of gymnasts has decreased over the years.

Reviews of the somatotype data on female gymnasts indicate several trends that distinguish competitive gymnasts from reference samples. Mesomorphy is, almost without exception, the dominant component and ectomorphy is greater than endomorphy. This somatotype is identifies an ectomorphic mesomorph and it differ from the unathletic females. A review of published data on mean somatotype of female gymnasts shows a trend of decreasing endomophy rating among international competitors between the Mexico Olympics in 1968 (endo : 2.7) and the World Championship in 1987 (endo : 1.8) (Claessens et al, 1999).

Body composition, changing characteristically not only according to age and sex but also according to the balance of energy input and output and functional state, has become one of the most interesting morphological features of human physique. Body composition, anthropometric dimensions, and morphological characteristics play a vital role in determining the

2.3 Studies Regarding the Cardiovascular Fitness of Athletes:

An athlete's ability to perform is based on the ability to gain needed energy (Astrand et al, 1968; and Chundawat, 2008).

Ann (1961) studied 93 women students of physical education using three minute step test to assess their cardiovascular efficiency and reported that training has influence on the cardiovascular fitness. According to Johnson (1975), a person who has improved his step-test scores by training is considered to have increased in circulo-respiratory fitness.

Thoden (1991) proposes that aerobic training may enhance the ability of the muscle to recover following anaerobic exercise, suggesting that an athlete with higher fitness will tax non-oxidative sources less and thereby recover at a more rapid rate from exercise.

Debasish and khanna (1992) studied the motor ability and cardio respiratory efficiency of state level basketball and volleyball players. The results found PFI (HST) of volleyball
players 79.80 and basketball players as 81.60. *Dawson et al* *(1993)* reported significant correlations between VO$_2$ max. and anaerobic performance.

*Tan et al (2000)* studied 42 elite bowlers (26 males and 16 females) to see the correlations between physiological parameters and performance. The aim of this cross-sectional study was to determine if age, height, weight, aerobic power index, bowling grip strength and the sit-and-reach distance correlated with bowling performance. The results showed that for the male bowlers, none of the parameters correlated with performance, while for the female bowlers, the only parameter that correlated with performance was the aerobic power.

In order to examine the physical and physiological demands of water polo, *Yiannis et al (2005)* assessed the profile of elite water polo players. Nineteen male professional water polo players (age: 25.5±5.0 years, mean height: 184.5±4.3 cm mean body mass: 90.7±6.4 kg) underwent body composition assessment by dual-energy X-ray absorptiometry. Body fat (%) and lean mass was found to be 16.8±4.4, and 75.1±4.9 kg respectively. Internal rotator muscles were stronger compared to the external rotators by a 2:1 ratio. The study provided a quantitative representation of both physical and physiological
demands of water polo and proposed a comprehensive battery of tests that can be used for assessing the status of a team.

Gabbett and Georgieff (2007) investigated the physiological characteristics of junior volleyball players and found them to possess greater standing reach height, speed, agility, muscular power, and estimated maximal aerobic power than female players. These findings provide normative data and performance standards for junior volleyball players competing at the elite, semi-elite, and novice levels.

2.4 Studies Regarding the Cardiovascular Fitness of Gymnasts:

Bosco (1973) reported that champion gymnasts have lower heart rates and blood pressure. According to Black and Johnson (1975), champion gymnasts were found to possess lower heart rate and blood pressure, which is considered to be the outcome of cardiovascular fitness invoked by interval training.

Kamal (1982) measured the Harvard Step Test of male and female Indian gymnasts before and after a six week training programme. The following differences were revealed:
### Initial Results | Final Results
---|---
**Men** | **Women**
85.0 (+8.29) | 84.9 (+5.03) | 95.13 (+6.17) | 89.11 (+6.47)

Debnath (1983) while studying the Indian female gymnasts found a significant correlation \((r= 0.8548)\) between Harvard Step Test and competitive performance in case of better performance group. Moffat et al (1984) examined the female gymnasts and revealed that the two female gymnasts exhibited higher on VO\(_2\) max. value and performed better on tests to estimate anaerobic capacity power output than the controls. Goswami and Gupta (1998) studied the cardiovascular stress and lactate formation during gymnastic routines. The results of the study indicated that in all the routines, peak heart rate was lower than maximum heart rate (HR Max) of the gymnasts. Mean heart rate was found lowest in first set and highest in the final (3\(^{rd}\) set) on all the apparatuses. Highest mean HR was recorded in Horizontal bar followed by floor exercises, roman rings, parallel bars and pommelled horse respectively. It was also found that after both first and third sets blood lactic acid was highest in floor exercises followed by roman rings, parallel bars, horizontal bar and pommelled horse and concluded that gymnastics activity is dominated by anaerobic metabolism.
One study by Jemni et al (2000) looked at heart rate (HR) response to a men’s gymnastics competition and concluded that high-performance gymnasts required a high HR (~179bpm) during a very short time period. It was found that there were differences between the heart rate achieved for each piece of apparatus, however most recorded values were between 158bpm and 170bpm. In terms of apparatus specific HR, the floor routine caused the highest peak HR value (~186bpm), closely followed by the high bar and the pommel horse routines (~185bpm). The parallel bars routine elicited a peak HR of ~180bpm and vaulting caused HR to reach ~162bpm. Unfortunately, no peak HR data was reported for the rings. The fact that the peak HR achieved during the routines was much lower than maximal HR was supportive of the earlier study carried out by Goswami and Gupta (1998). From the HR traces recorded during the competition, Jemni and colleagues were also able to establish the most used HR ranges for each piece of apparatus which are presented in the following table.

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<thead>
<tr>
<th>Apparatus</th>
<th>Floor Ex.</th>
<th>Pommel Horse</th>
<th>R.Ring</th>
<th>Vaulting Table</th>
<th>P. Bars</th>
<th>Horizontal Bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR range (bpm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Therefore, it is apparent that, certainly in the men’s discipline, each piece of apparatus has its own physiological requirements and it can be assumed that a similar pattern would exist in women’s gymnastics.

**Bencke et al (2002)** studied and compare the anaerobic power and muscle strength of gymnasts, handball, tennis players and swimmers. The anaerobic performances were assessed by Wingate tests and jumping performance in squat jump (SJ), counter movements jump (CMJ) and drop jump (DJ) from two heights. The gymnasts were found to be the best jumpers.

**Jemni et al (2006)** studied aerobic and anaerobic performance of the upper body (UB) and lower body (LB) of the gymnasts who were assessed by arm and treadmill tests respectively in a comparison of national (N) and international (I) male gymnasts. Force velocity and Wingate tests were performed using cycle ergometers for both arms and legs. In spite of a significant difference in training volume (4-12 vs. 27-34 h.wk (-1 for N and I, respectively), there was no significant difference between N and I in aerobic and anaerobic performance.

To identify the physiological and anthropometric predictors of rhythmic gymnastics performance thirty-four rhythmic
gymnasts (elite N = 15 and non elite N = 19) were studied by Douda et al (2008). They underwent a battery of anthropometric, physical fitness and physiological measurements. The principal-components analysis extracted 6 components: anthropometric, flexibility, explosive strength, aerobic capacity, body dimensions, and anaerobic metabolism. It was found that components of anthropometric (r = .50) and aerobic capacity (r = .49) were significantly correlated with performance (p < .01). It was concluded that selected anthropometric characteristics, aerobic power, flexibility, and explosive strength are important determinants of successful performance.

2.5 Studies pertaining to Motor Abilities of Athletes:

Motor ability is an ability that is specifically related to the performance of motor skill. Since movement is the biological necessity of every human being, especially of a child, it is necessary, particularly in urban areas to satisfy this necessity by means of organized physical activities. Development of motor abilities and functional characteristics is of vital importance for the progress and development of athletes. A good understanding of the basis and demands of each and every sport implies the
incorporation of exercises for the development of individual motor abilities and functional characteristics.

**Bosen et al (1984)** compared the physical fitness of 24 Indian men javelin throwers with international norms and concluded that Indian throwers were lacking in specific strength, jumping explosive strength of trunk and pulling muscles as compared to international norms.

**Beunen et al (1988)** collected data on a large representative sample of 9700 Flemish girls aged 6 to 18 years to investigate the relationship between skeletal age and different components of physical fitness and found a significant correlation of balance, speed of limb movement, running speed, endurance run, explosive leg strength, trunk strength and flexibility.

**Lida et al (1988)** compared the physical fitness between Korean and Japanese college judoists and found that Japanese judoists were significantly superior in physique and static strength whereas, Korean judoists were found to be superior than their Japanese counter parts in leg strength and grip strength.

**Lee and Brucer (1989)** studied the flexibility characteristics of 24 male and 22 female Unites States National
Olympic volleyball players. Shoulder and hip flexibility was compared to the jumping height of the players. A significant and positive correlation was found between AVJ (approach vertical jump) and hip flexibility for men \((r=0.42)\), for women a significant and negative correlation was found between AVJ and hip flexibility \((r=-0.54)\).

Pireira and Matsudo (1998) determined the fitness profiles of Brazilian top female judoists as related to sports success. Authors concluded that there was relationship between 40 sec. run and success.

Eadric et al (2007) compared the static and dynamic balance in female collegiate soccer, basketball and gymnasts. The female basketball players demonstrated inferior static balance compared with gymnasts and inferior dynamic balance compared with soccer players. No differences in static or dynamic balance were seen between gymnasts and soccer players.

Singh et al (2008) collected data on 30 female soccer players to know the relationship of leg and back strength on high drive kick. It was concluded that strikers and mid fielders were significantly superior in strength and significant correlation has been espied between leg and back strength.
Singh et al (2009) studied the 36 volleyball players of different countries who participated in volleyball World championship in 2006. The study was conducted to find out the relationship of scoring skills with maximum spike jump and maximum block jump test performance. The findings concluded that success rate in scoring skills at 5 centimetres internal of height indicate that the players having the height between 201 to 205 centimetres have the highest success rate in spike; whereas the players with height between 190 to 195 centimetres have better success rate in serve and block.

2.6 Studies Pertaining to Motor Abilities of Gymnasts:

Artistic gymnastics is a highly skilled sport which incorporates the women's events of vaulting table, uneven parallel bars, balancing beam and floor exercises. The development of skills necessary for the elite performance, take years of intense practice and requires to totally committing their lives to the sport. Gymnastics is a unique sport in terms of the physical demands placed on the body during training and competition. The strength, agility, flexibility and stamina of each competitor are on constant display and the slightest miscue can be the difference between a gold medal and no medal at all.
Bosco (1973) reviewed the physical and physiological characteristics of champion male gymnasts and found them to possess less superficial fat, more strength, more flexibility, better balance, more agility, more explosive power and a faster reaction time.

Haywood (1980) studied the strength and flexibility in gymnasts before and after menarche. According to her, no evidence was found that gymnasts in training decline in their performance on strength and flexibility tasks after menarche as compared to pre-menarche gymnasts of similar age and skill.

Bawa (1981) conducted study on 79 (43 men, 36 boys) national level male gymnasts. The gymnasts were divided into four groups according to their performance. He reported that the gymnasts of excellent group were more muscular, stronger, flexible and powerful then the lower level gymnasts. He further reported that the Indian gymnasts are less developed in terms of lean body mass as compared with the American and Japanese gymnasts.

Beunen et al (1981) conducted the motor ability tests on 23 Belgium female gymnasts and compared them with 450 school girls. Female gymnasts earned extremely high scores in flexibility and in trunk strength (leg lifts). Their results in
explosive strength (vertical jump), static strength (arm pull) and functional strength (bent arm hang) were also above average than the school girls.

Sixty competitive female gymnasts and 35 age-matched non-athletes were measured by Kirby et al (1981) on flexibility and musculoskeletal symptomatology. It was found that a significantly great number of gymnasts (p < 0.01) had musculoskeletal symptoms in the wrist, low back, hip, shin and foot regions than did the controls. Gymnasts were found to have greater shoulder flexion and horizontal abduction, lumbar flexion and horizontal abduction, hip extension and toe-touching abilities (p < 0.001). However analysis suggested trends indicated that the low injury subjects were more flexible (back extension and ankle (dorsi flexion) than those who had reported more injuries (both p = 0.013). Independent t-tests revealed that between groups of low and high injury rates, there were significant differences in age (p = 0.002), stature (p = 0.006) and body mass (p = 0.002).

Walia (1981) conducted a study of correlation between strength, flexibility and performance of 46 Indian gymnasts and observed that approximately 83% of performance in gymnastics depends collectively upon strength and flexibility.
Kamal (1982) studied the effect of a six week special training programme on 16 male (23 years) and 17 females (16 years) national gymnasts. The gymnasts were measured before and after the training. He concluded that male and female gymnasts significantly improved their physical fitness, static back strength, grip strength (right and left), Sargent jump, standing broad jump, bench press, trunk extension, dips on parallel bars and leg raising as a result of participation in vigorous training. The women gymnasts scored significantly lesser (p <0.05) in final tests in resting heart, 50 metre sprint than the initial tests. No significant difference between final and initial tests in body weight of women gymnasts was observed.

Physical and physiological variables of swimmers, badminton players and gymnasts were compared by Mangala (1982). He found the gymnasts to be better than badminton players in back strength, broad jump, Sargent jump, medicine ball throw, 50 metre dash and flexibility but in grip strength badminton players were equal to gymnasts. As compared to swimmers, gymnasts were found to be better in back strength, grip strength and 50 metre dash and equal in Sargent jump, broad jump, medicine ball throw and in agility tests.

Debnath (1983) conducted a study of inter relationship between motor abilities and performance of 27 female gymnasts
of India. According to their performance they were divided into two groups (i.e. top level and lower level gymnasts). Significant differences were found between the two groups in pull-ups, back lift, standing broad jump, 50 metre sprint, Harvard Step Test, trunk extension and balance ability. A significant negative correlation of \( r = -0.775 \) between 50 metre sprint and competitive performance was found.

**Sodhi and Singh (1983)** studied the 44 outstanding male gymnasts. The data of 44 gymnasts was divided into two groups: those selected for the 9th Asian Games formed group A, and the other entire formed group B. The gymnasts of each group were compared with a control sample \((N = 42)\), as well as the Olympian reported elsewhere. Each subject was examined with dips on parallel bars, sit-ups, standing broad jump, trunk flexibility, and score achieved through competitive performance. The results of the study indicated a significant correlation of competitive performance with the dips, sit-ups and the trunk flexibility. The Indian high performance gymnasts in group A were found to be stronger in sit-ups and standing broad jump than the poorer ones in group B.

**Walia (1985)** studied the physical and physiological profiles of Indian male gymnasts. He observed that better
competitive performance in gymnastics depends upon the level of physical and physiological abilities and further stated that leg raising on wall bars (abdominal strength), Sargent jump (explosive leg strength), hip flexibility and technical performance has vital role to play in gymnastic performance.

In a study of pubescent boys, conducted by Berg et al, 1986 (mean age = 11.8 ± 0.31 yr), found the relationship of height to 30 metre sprint time (r = -0.19) and mass (r =0 .23). Haywood et al (1986) conducted study on 121 female gymnasts and 55 female swimmers and found that gymnasts were having more trunk flexibility and greater pulling strength than the swimmers. Sands and Cheetham (1986) showed a modest relationship (r = 0.69, p < 0.05) between score and vault maximum run-up speed (7.25 ±0.25 m/s) in junior elite female gymnasts (age 12-14 yr). Sands and Cheetham (1986) studied the velocity of the vault run using high speed film and noted a high relationship between peak run speed and vault score in a variety of vaults(r (9) = .953, p < .05) and found the average run-up velocity of female gymnasts as 7.25 m/s on a variety of vaults.

Faria and Faria (1989) measured 65 male class I and II gymnasts on power, strength and flexibility test. The top ten
gymnasts (Class I) were found to be stronger in relative and absolute strength, possessed greater flexibility through the hip region, shoulder girdle and back. It was concluded by Singh and Debnath (1989) that there is significant contribution of arms, shoulders, abdominal and leg strength to competitive performance in men gymnasts. They found a significant correlation coefficient between performance and Sargent Jump ($r = 0.568$), arm strength ($r = 0.558$), hand stand dips ($r = 0.650$) and chin-ups ($r = 0.568$).

Uppal and Gill (1989) conducted a study on a sample of 80 male gymnasts ranging in age from 18 to 33 years at 27th National Gymnastic Championship held at Jabalpur. The analysis of data revealed that performance in gymnastics is significantly related to arm strength ($r=0.37$), abdominal strength ($r=0.30$), right grip strength ($r=0.51$), left grip strength ($r=0.47$) and explosive leg strength ($r=0.39$). Hence it is possible to predict gymnastic performance on the basis of strength variables. Further the multiple correlation of ($r=0.68$) indicates that in order to predict performance in gymnastics, instead of depending only upon a single variable, all the variables may be given due consideration.
Takei (1990) found a significant correlation (r=.74) in a study of the handspring compulsory vaults of female gymnasts at the Pan American Games between take off velocity and score. He noted that the take off velocity from the board may differ significantly from the maximum run-up velocity. For example, analysis of two female gymnasts from the 1984 Olympic Games showed that horizontal component board touch down velocity of the gymnasts following a round off entry was 5.1 to 5.5 m/s. Clearly, the round off prior to board contact will result in considerable slowing of the gymnast’s overall run-up speed.

A study conducted by Debnath and Bawa (1991), on coordinative abilities and flexibility level of Indian national women gymnasts revealed that high performance group possess greater trunk and hip flexibility than the other mediocre and low performance group. Similar results have been reported for sub-junior female gymnasts also (Debnath and Bawa, 1989).

Sharma (1992) conducted study on eight national level gymnasts to find out the effect of speed, take-off and hand push-off ability on selected biomechanical parameters in vaulting event of artistic gymnasts. The speed ability of the gymnasts was measured cinematographically by determining maximum running velocity on 25 metre distance. The standing vertical
jump was chosen to measure the take off ability of the gymnasts. He found a very high correlation between the speed ability of the gymnast and his achieved horizontal approach run velocity with the performance of the vault (handspring salto vault, r = .934 (1% level of significance) and with Tsukahara vault (r = .833). The comparison of the results indicated that better gymnasts in vaulting performance were better in their level of speed, take-off and hand push-off abilities than poor gymnasts.

Gurdial and Kalpana (1995) conducted study on 36 sub junior national level male gymnasts to describe the physical performance attributes. A battery a tests which included age, weight, height, dips on parallel bars, pull ups on horizontal bar, standing broad jump, vertical jump, sit-ups with jack knife action, 30 metre sprint, trunk flexion and hip flexibility was administered on each gymnast. The results of the investigation have shown that high performance group was significantly better than the mediocre performance group in dips on parallel bar, pull ups on horizontal bar and competition performance. High performance group has also been found to possess significantly greater legs power, greater hip flexibility than the lower performance group of gymnasts.
Krug et al (1998), using a laser speed measurement system found the speed of handspring-type vaults averaged 7.3 m/s, Yurchenko-type vaults averaged 6.98 m/s, and Tsukahara-type vaults averaged 7.28 m/s. In order to study the maximum vault run speeds of top American female gymnasts, run-ups were recorded by Sands (2000) during the 1999 John Hancock U.S. Gymnastics Championships in Sacramento, Calif. The radar gun was used to record vault run-up speeds without interacting with the gymnast. Multiple trials of the same vault were then averaged.

The Results were found as under:

**Descriptive Statistics Speeds (m/s)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Min.</th>
<th>Max.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All Gymnasts/All Vaults</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handspring-Type</td>
<td>7.28</td>
<td>0.39</td>
<td>6.48</td>
<td>7.91</td>
<td>23</td>
</tr>
<tr>
<td>Yurchenko-Type</td>
<td>7.21</td>
<td>0.40</td>
<td>5.99</td>
<td>7.75</td>
<td>67</td>
</tr>
<tr>
<td>Tsukahara-Type</td>
<td>7.36</td>
<td>0.34</td>
<td>6.48</td>
<td>7.87</td>
<td>9</td>
</tr>
<tr>
<td><strong>Senior Gymnasts</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handspring-Type</td>
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<td>0.22</td>
<td>7.33</td>
<td>7.9</td>
<td>1.7</td>
</tr>
<tr>
<td>Yurchenko-Type</td>
<td>7.36</td>
<td>0.35</td>
<td>5.99</td>
<td>7.75</td>
<td>43</td>
</tr>
<tr>
<td>Tsukahara-Type</td>
<td>7.51</td>
<td>0.51</td>
<td>6.48</td>
<td>7.87</td>
<td>6</td>
</tr>
<tr>
<td><strong>Junior Gymnasts</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handspring-Type</td>
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<td>0.36</td>
<td>6.48</td>
<td>7.73</td>
<td>23</td>
</tr>
<tr>
<td>Yurchenko-Type</td>
<td>6.93</td>
<td>0.34</td>
<td>6.30</td>
<td>7.47</td>
<td>24</td>
</tr>
<tr>
<td>Tsukahara-Type</td>
<td>7.19</td>
<td>0.23</td>
<td>7.05</td>
<td>7.53</td>
<td>4</td>
</tr>
</tbody>
</table>
**Bradshaw (2004)** studied the target directed running in gymnastics on five elite gymnasts in the age group of 13-15 years who performed five round-off entry vaults. Video cameras were used to record the approach step, hurdle, round-off characteristics and performance on the vaulting table. Two judges were appointed to judge the performance. It was discovered that high take-off velocity was directly related to judge's score (p=0.03).

**Kalpana and Bawa (2004)** studied 22 female gymnasts who attended 6 weeks coaching camp at NIS, Patiala. The tests to measure physical abilities level were chin ups, dips, rope climbing, raising legs on wall bars, sit ups, standing broad jump, vertical jump, trunk flexion and 30 metre sprint. Gymnastics competition performance was administered on each subject at the end of coaching camp. Again the same tests were conducted after training break of 8 weeks on the same subjects. The results have shown a significant decrease in physical abilities level, especially in arms strength, abdominal strength and explosive leg strength, flexibility and competition performance scores after the break in training.

**Ann et al (2007)** analyzed and compared the isokinetic muscle performance of the scapular muscles between elite
adolescent gymnasts ($N = 16$) and non athletes ($N = 26$). The elite gymnasts demonstrated increased protraction strength and altered muscle balance around the scapula compared with non-athletes. It was concluded that adaptation in the scapular muscles may influence the quality of gymnastic performance and the risk for overuse injuries in other body parts.

**Frederick et al (2007)** studied balance and stability between elite level gymnasts and non-gymnasts. The results of postural stability have shown that gymnasts have greater postural stability than non-gymnasts and it may contribute to increased sports performance and decreased probability of injury.

**Suncisa et al (2007)** measured the effects of biometer structure on performance of competitive gymnastics. Various tests to assess motor abilities and morphological characteristics were conducted on 127 female gymnasts (Mean aged 12 years). The relations of motor abilities and morphological characteristics with gymnastics elements performance in elementary school female sixth graders were found similar to those found in elite female gymnasts.

**Kinser et al (2008)** tested the 22 junior female gymnasts to know the effect of vibration and stretching on flexibility and
explosive strength in young gymnasts. The results concluded that vibration and stretching had greatly increased flexibility while not altering the explosive strength.

The scientific evidences obtained from various investigations in the past have revealed that champion gymnasts are being identified with special characteristics such as shorter in stature, lighter in weight, less superficial fat, more strength, more flexibility, more explosive power, more speed and lower heart rate.

The particular biomechanical characteristics of the athletic movements, which are typical in gymnastics, favour and selects subject who are well-proportioned but small and thin, and have a good muscular endowment and so are able to express themselves with favorable neuro-muscular coordination, as required by this particular sport discipline. After reviewing critically literature, it has been found that scholarly attempts have been made separately to investigate the relationship of physique, motor fitness components and other variables to performance in gymnastics; however, no study regarding the morphological, physiological and motor abilities has so far been conducted on All India Inter University level female gymnasts.
The studies mentioned above stimulated the present investigator, the aim of which was to determine the relationship of morphological, physiological and motor abilities with performance of female gymnasts.