REVIEW OF LITERATURE

Review of literature plays a very important role for any research work to be carried out. In the present study, an extensive literature search was done from internet websites like Pubmed, Sciencedirect.com as well as from the libraries of Guru Nanak Dev, University, Amritsar and National Medical Library, New Delhi.

2.1 Handgrip Strength in Normal Populations

De et al. (1979) conducted simple anthropometric measurements and physical efficiency tests on adolescent Indian urban boys between 10-14 years and girls between 11-14 years of age. The similar height and weight of the subjects of both sexes were observed suggestive of higher growth rate in girls than the boys during only the initial phase of adolescent growth spurt. The vital capacity, peak expiratory flow rate and grip strength were observed to be insignificantly different between the sexes.

Chatterjee and Chowdhuri (1991) assessed maximum handgrip strength and endurance of fatiguing isometric handgrip muscle contraction at 40 percent of maximum voluntary contraction of the dominant hand separately for both right and left hands of 99 right-handed men aged 7-73 years. Grip strength was positively correlated with the weight (r = 0.86 right and r = 0.87 left), height (r = 0.88 right and r = 0.87 left) and body surface area (r = 0.9 for both) of the subjects. Endurance of contraction of both hands did not show any relationship with age, different physical parameters or grip strength of the subjects.

Reed et al. (1991) measured maximal grip strength in kilograms using a hand dynamometer on 344 unrelated males between the ages of 59 and 70 participating in the third examination of the National Heart, Lung and Blood Institute Twin Study. A significant linear decline in mean grip strength over this age range was found. Mean grip strength and grip strength per kilogram weight were presented for age 59, ages 60-64 and 65-69. Genetic analysis using 127 pairs of identical twins and 130 pairs of fraternal twins indicated significant genetic effects for absolute grip strength and grip strength per kilogram weight. The largest estimate of heritability (65 percent) was obtained for grip strength adjusted for significant effects of weight, height, age, and various anthropometric measures of fatness, muscle mass, and frame size.
Shiffman (1992) conducted a study examining relationships between prehension pattern type and frequency, hand strength, and performance time in functional tasks. Four groups of 10 adults (24-87 years) were selected by age and gender. Prehension patterns were identified with a functionally based classification system. Grip and three types of pinch were measured with a dynamometer and a pinch gauge. Results showed that prehension pattern selection did not seem to differ with age. However, statistically significant differences in age were found for prehension pattern frequency, hand strength, and performance time. Non-dysfunctional older subjects were observed resetting identical prehension patterns secondary to lateral pinch weakness, which contributed to increased prehension pattern frequency and performance time. Hand function seemed to remain stable until age 65 years, after which it diminished slowly. After age 75 years, age differences in performance were most apparent.

Crosby and Wehbé (1994) studied normal hand strength and the difference between dominant and non-dominant hands. They tested 214 volunteers with a calibrated jamar dynamometer at all five levels. A pinch gauge was used to assess key and pulp pinch. Height, weight, sex, hand dominance, and hobby demands were predictive of maximum grip. Results showed that mean maximum grip was 81 lb and 137 lb for women and men respectively. Key pinch averaged 22 percent, while pulp pinch averaged 16 percent of maximum grip. Only 129 (60 percent) subjects had maximum strengths at level 2. The majority of right-handed subjects were 10 percent stronger in grip strength on the dominant side. In left-handed subjects, mean grip was the same for both hands; the non-dominant hand was stronger in 50 percent of left-handed subjects.

Desrosiers et al. (1995) examined the grip strength of 360 subjects aged 60 years and older, randomly recruited by age and gender strata, evaluated with the Jamar dynamometer and the Martin vigorimeter. They concluded that grip strength diminishes curvilinearly with age and men were consistently stronger than women.

Benefice and Malina (1996) determined the relationships between anthropometric dimensions (stature, weight, arm and calf circumferences, and four subcutaneous skin folds), and motor performances (dash, standing long jump, throw for distance and grip strength) among children aged 5-13 years. It was found that medians at each age, and
deviations were more pronounced in children less than 8 years of age and in boys more than girls. Boys, on average, performed better than girls on all tasks.

Rantanen et al. (1999) determined whether handgrip strength measured during midlife predicts old age functional limitations and disability in initially healthy men. A 25-year prospective cohort study was performed on a total of 6089 (45-68 year old) men who were healthy at baseline and whose maximal handgrip strength was measured from 1965 through 1970. A total of 3218 survivors participated in the disability assessment in 1991 through 1993. After adjustment for multiple potential confounders, risk of functional limitations and disability 25 years later increased as baseline handgrip strength declined. It was concluded that handgrip strength was highly predictive of functional limitations and disability 25 years later.

Carmelli and Reed (2000) investigated aging-related changes in the contribution of genetic and environmental influences to handgrip strength in late adulthood. 152 twin pairs from the National Heart, Lung, and Blood Institute Twin Study were assessed repeatedly for handgrip strength at mean ages of 63 and 73 years. Stability and change in the genetic and environmental components of variance of handgrip strength in late adulthood were investigated. A highly significant (p = 0.003) average decline in strength over the 10 years of follow-up was -1.05 +/- 6.8 (SD) kg found. The test-retest correlation between baseline and follow-up grip strength was 0.62 (p<0.001). Bivariate genetic modeling found significant genetic and shared environmental stability in handgrip strength over the 10 years of follow-up, with genetic and shared environmental influences accounting for 35 and 48 percent, respectively, of the test-retest phenotypic correlation. It was concluded that stability in handgrip strength in late adulthood is due primarily to continuity of genetic and familial influences.

Ellis et al. (2000) carried out a study on 86 children and youth enrolled at a residential school for the deaf who were matched with 86 children and youth with normal hearing (by age, sex, height, weight, and hand preference) from four public schools. Each participant's grip strength was tested with a calibrated hydraulic dynamometer set at the second position. No significant between-group differences were observed. The similar between-group performances were attributed to the equal opportunities for participation in sport and physical education in this residential school.
Ho *et al.* (2000) established normative data for handgrip and key pinch strength for 15 to 22 year old Chinese students. The Jamar dynamometer and Jamar pinch gauge were used to measure grip strength and key pinch strength respectively. Out of a total of 2,982 students examined, there were nine men (0.39 percent) who used the left hand for writing, 143 men (6.27 percent) who used the left hand during exercise, two women (0.28 percent) who wrote with the left hand and 26 women (3.70 percent) who used the left hand during exercise. The mean grip and key pinch strength of the left hand was about 90 percent that of the right hand. The mean grip and key pinch strength of the women was about 60 percent that of men. A strong correlation between the right hand and the left hand in grip and key pinch strength was found.

Hunter *et al.* (2000) investigated the magnitude and rate of age-associated strength reductions in Australian independent urban-dwelling women and the relationship to muscle groups, limb dominance, and physical activity level on urban-dwelling women aged 20 to 89 years (n = 217). They performed maximal voluntary contractions with the dominant and non-dominant knee extensors, plantar flexors, and handgrip along with various anthropometric measurements. Limb muscle strength was found to be associated with increased age, muscle group, limb dominance, and activity. Self-reported physical activity levels decreased with age but women who were more physically active for their age group were stronger in all muscle groups and had more lean body mass and lean thigh and leg cross-sectional area than relatively inactive women. The limb muscle strength of women was found to be associated with age and three aspects of disuse: muscle group, relative levels of physical activity, and limb dominance. Age was the most potent predictor of muscle strength, and even the strongest women in each age group were unable to maintain the strength of the young women.

Hulthe´n *et al.* (2001) evaluated the importance of growth hormone for lean mass and muscle strength in adolescents and young adults. 250 healthy adolescents were randomly selected for prospective measurements of lean mass and handgrip strength between the ages of 17 and 21 years. Growth hormone treatment was discontinued in 40 adolescents aged 16-21 years with growth hormone deficiency of childhood onset. Isometric and isokinetic knee-extensor and flexor strength, handgrip strength, lean body mass, fat-free mass, and total body nitrogen were performed annually for 2 years.
Adolescents who had continuous growth hormone deficiency, showed a decrease in lean body mass as compared with the patients defined as having sufficient endogenous growth hormone. The isometric strength in knee flexors increased in the sufficient endogenous growth hormone group and was unchanged in the growth hormone deficiency group during the 2 year off growth hormone treatment (between group, p < 0.05). The mean and peak handgrip strength increased on average by 9-15 percent in the group with sufficient endogenous growth hormone and was unchanged in those with growth hormone deficiency (p < 0.05). Lean body mass and handgrip strength (both, p < 0.001) increased in both the healthy boys and girls who were followed for 4 years with a more marked increase in the boys. The mean increase in handgrip between the age of 17 and 21 years was 7-9 percent. The increased lean mass and improved muscle performance seen in healthy adolescents did not occur in adolescents with growth hormone deficiency.

Ranganathan et al. (2001) examined age-induced changes in handgrip and finger-pincho strength in healthy, independent, young (n = 27, range 20-35 years) and older (n = 28, range 65-79 years) subjects. Handgrip strength, maximum pinch force (MPF), ability to maintain a steady pinch force at three relative force levels (5 percent, 10 percent and 20 percent MPF) and three absolute force levels (2.5 Newtons (N), 4N, and 8N), ability to maintain a precision pinch posture, speed in relocating pegs from a nearby location onto the pegboard, and the shortest distance for discriminating two stimuli were measured in both young and older groups. The older group's handgrip force was found to be 30 percent weaker (p< 0.001), MPF was 26 percent lower (p<0.05), and ability to maintain steady submaximal pinch force and a precision pinch posture was significantly less (p< 0.05) as compared with the young subjects. The time taken to relocate the pegs and the distance needed to discriminate two identical stimuli increased significantly with age (p< 0.01). The decrease in the ability to maintain steady submaximal pinch force was more pronounced in women than men. Aging thus has a degenerative effect on hand function.

Zverev et al. (2001) compared the anthropometric measurements of the urban school children (aged 6-17 years) in Malawi with data from the region of South-Central Africa and international standards. Expressed as percentage of WHO/NCHS references, the relative means of height, weight, mid-upper arm circumference and mid-upper arm
muscle circumference of Malawian girls were considerably higher than those of boys and mean maximal grip strength values of boys and girls were not significantly different. For girls, the relative values increased with age, while for boys they decreased.

Häger-Ross and Rösblad (2002) examined peak grip strength on 530 Swedish 4-16 years old with the instrument Grippit, over a 10 second period, and sustained grip strength averaging across the 10 seconds. Boys and girls showed an increase in grip strength with age approximately parallel until 10 years of age, after which boys were significantly stronger than girls. There was a strong correlation between grip strength and the anthropometric measures weight, height and, in particular, hand length. Right-handed children were significantly stronger in their dominant hand, while left-handers did not show any strength difference between the hands. It was therefore suggested that when evaluating grip strength in left-handed children, both hands should be assumed to be about equally strong, while right-handed children are expected to be up to 10 percent stronger with their right hand. Sustained grip strength was consistently about 80-85 percent of peak grip strength, with somewhat lower values in younger children.

Incel et al. (2002) evaluated the grip and pinch strength differences between sides for the right and left handed population and concluded that the dominant hand was significantly stronger in right handed subjects but no such significant difference between sides could be documented for left handed people.

Kuh et al. (2002) examined the relation between birth weight and handgrip strength in a prospective national birth cohort of 1,371 men and 1,404 women aged 53 years in 1999, from the Medical Research Council National Survey of Health and Development. A positive relation between birth weight and adult grip strength was found after adjustment first for adult height and weight and then additionally for childhood height and weight (p = 0.006 for men and p = 0.01 for women). The effects of birth weight on grip strength did not vary by childhood or current body size and were not confounded by social class. Results suggested that birth weight was related to the number of muscle fibers established by birth and that even in middle age compensating hypertrophy might be inadequate. As the inevitable loss of muscle fibers proceeded in old age, a deficit in the number of fibers could threaten quality of life and independence.
Kulaksiz and Gozil (2002) investigated the effect of hand preference on hand anthropometric measurements on 393 healthy university students. Seven hand parameters were evaluated for each hand. Higher values were observed for hand width and shape index for the right hand, but the palmar length/width ratio was found to be high for the left hand, for strong and weak right handers, respectively. No significant statistical values were observed for ambidextrous subjects, while non-significant reverse direction asymmetric values were found in the left-handed group. An increase in right and left hand asymmetry was established going from the strong right hand preferent group to the strong left hand preferent group (on a decreasing scale of right hand preference). Left hand shape index and right hand finger index increased in correlation with the tendency for left hand and right hand preference, respectively. The findings revealed that, environmental factors such as hand activity, hormones, and brain asymmetry may play a role in the effect of hand preference on hand anthropometric measurements. No difference in asymmetry in regard to the sex of the subjects was observed.

Pieterse et al. (2002) investigated the association between nutritional status and handgrip strength in older Rwandan refugees (413 men and 415 women aged 50-92 years). Weight, height, mid upper arm circumference and triceps skinfold were obtained using standard techniques. Results indicated that the handgrip strength (kg) was significantly higher in men than in women (30.3 years vs 22.3 years), and significantly lower in each older age group in both sexes. It was positively correlated to body mass index and arm muscle area. The relative risk of impaired handgrip strength in individuals with poor nutritional status compared with those of adequate nutritional status was 1.75. After controlling for potential confounders (sex, age and height), BMI remained a significant contributor to the variation in handgrip strength. Hence, it was concluded that poor nutritional status was associated with poor handgrip strength independent of sex, age and height, in this refugee population.

Sartorio et al. (2002) reported that age dependent increase of handgrip strength in boys and girls were strongly associated with changes of muscle mass during their childhood. They evaluated maximum handgrip strength, body composition and main anthropometric variables in 278 children with normal weight and growth. The children aged 5-15 years were divided into 3 age groups: group 1, age+/-SD: 7.6+/-0.9 years
Review of Literature

(Tanner stage: 1); group 2, age: 10.8 +/- 0.7 years (Tanner stage: 2-3); group 3, age: 13.2 +/- 0.9 years (Tanner stage: 4-5). It was observed that weight, height, body surface area, body mass index, percent body fat and fat free mass increased progressively and significantly from the younger to the older age group. A significant difference between genders was detected only for percent body fat and fat free mass, females having a higher fat mass and a lower fat-free mass compared to males.

Lee-Valkov et al. (2003) conducted a study to determine whether reproducible normative values for hand dexterity and grip and pinch strength could be obtained in young children using simple tests that could be administered quickly within the attention span of 3 to 5 year old. The functional dexterity test was used for dexterity and dynamometer for grip strength. They found that a good functional dexterity test score in the dominant hand was predictive of a good score in the non-dominant hand but grip and pinch strength correlated poorly with functional dexterity.

Peña Reyes et al. (2003) compared the physical fitness of rural (175 boys, 184 girls) and urban (163 boys, 161 girls) school children, aged 6-13 years resident in an urban colony and in a rural indigenous community in Oaxaca, southern Mexico, using performance-related fitness (standing long jump, 35-yard dash) and health-related fitness (grip strength, sit and reach, timed sit-ups, distance run). It was found that urban children were significantly taller and heavier than rural children. Absolute grip strength did not consistently differ between rural and urban children, but when adjusted for age and body size, strength was greater in rural children.

Bailey and Hurd (2005) examined the relationship between trait aggression using a questionnaire, and finger length ratio in both men and women. Men with lower, more masculine, finger length ratios had higher trait physical aggression scores (p = 0.028). They found no correlation between finger length ratio and any form of aggression in females.

Luna-Heredia et al. (2005) measured grip strength on 517 healthy volunteers (267 females and 229 males) aged 17-97 years, using two different handgrip dynamometers. Three consecutive measurements were made in both the dominant and the non-dominant hands. Results demonstrated that the handgrip strength was dependent on gender (non-dominant hand: 22.8 +/- 7.2 kg in females and 35.1 +/- 12.4 kg in males, t test p<0.0001)
and was negatively correlated with age (females $r = -0.60$, males $r = -0.67$, $p<0.01$) and positively with height (females $r = -0.48$, $p<0.01$, males $r = -0.60$, $p<0.01$).

Nicolay and Walker (2005) examined grip strength and endurance in three experiments: single-repetition, 10-repetition, and 30 second static hold. They assessed relationships between anthropometric variation and grip performance for 51 individuals, aged 18-33 years and found forearm and hand measurements to be better predictors of grip strength than height and weight. The ability to predict strength was most accurate for the single-repetition, and then declined with increasing duration of the experiment. In contrast to strength, anthropometric variation was completely unassociated with relative grip endurance (percent change in force production). While larger males produced greater average grip force than did females, no significant differences existed between the genders in measures of relative endurance. The dominant hand was found to be significantly stronger than the opposite hand, but it also fatigued more rapidly. This trend was more pronounced in females than in males.

Leyk et al. (2007) determined maximal isometric handgrip strength in 1,654 healthy men and 533 healthy women aged 20-25 years. To assess the potential margins for improvement in handgrip strength of women by training, they studied 60 highly trained elite female athletes from sports known to require high handgrip forces (judo, handball). Mean maximal handgrip strength showed the expected clear difference between men (541 N) and women (329 N). 90 percent of females produced less force than 95 percent of males. Though female athletes were significantly stronger (444 N) than their untrained female counterparts, that value corresponded to only the 25th percentile of the male subjects. Handgrip strength was linearly correlated with lean body mass. Furthermore, both relative handgrip strength parameters ($F_{\text{max}}$/body weight and $F_{\text{max}}$/ lean body mass) did not show any correlation to hand dimensions.

Vianna et al. (2007) investigated the effect of gender and age on handgrip strength. A sample of 2,648 subjects (1,787 men and 861 women), aged between 18 and 90 years were selected for the study and their handgrip strength was measured. Men showed higher handgrip strength as compared with women. The regression analysis with a quadratic model showed that aging accounted for 30 percent of the variance in handgrip strength ($r = 0.30; p < 0.001$) in men and 28 percent ($r = 0.28; p < 0.001$) in women and a
faster decline in handgrip strength occurred at the age of 30 years for men and 50 years for women. It was concluded that handgrip strength declined with age differs between genders.

Budziareck et al. (2008) determined handgrip strength of 300 well nourished subjects, aged 18-90 years, using a hand dynamometer. Adductor pollicis muscle thickness and other anthropometric variables were also measured and the results were analyzed according to gender and age group. Multiple linear regression was also carried out in order to identify significant determinants of handgrip strength. Results indicated significant association of handgrip strength with gender and its decrease after age 60 years (p < 0.001). Adductor pollicis muscle also showed a strong correlation with handgrip strength ($R^2 = 0.71$ and 0.70, for dominant handgrip strength and non-dominant handgrip strength respectively). This association remained significant after adjustment for other variables such as gender, age and body mass index.

Godina et al. (2008) cross-sectionally investigated 255 boys, aged from 14 to 17 years from Moscow Suvorov Military School and the results were compared with the previously investigated students of Moscow municipal schools and those of special sports schools of the same age range. Various anthropometric measurements, evaluation of sexual maturation indices, somatotypes, diastolic and systolic blood pressure, pulse rate, handgrip etc. were measured. The military school students were found to be more brachimorphic and brachicephalic, having longer period of growth, and bigger annual increases in circumferences and weight, while in boys from municipal schools the values of these characteristics decreased.

Koley et al. (2008) associated handgrip strength (both left and right) with height, weight and BMI in randomly selected 600 normal healthy individuals (300 boys and 300 girls) aged 6-25 years of Amritsar, Punjab. Results indicated a strong association of right and left handgrip strength with height, weight and body mass index. It was concluded that an increase in handgrip strength determined the physical strength of an individual.

Milliken et al. (2008) conducted a study on ninety children (39 girls and 51 boys) between the ages of 6.7 and 12.3 years. They were tested on 1RM chest press (CP) strength, 1RM leg press (LP) strength, handgrip strength, vertical jump, long jump, sit and reach flexibility, and height and weight. For the combined sample, LP 1RM ranged
from 75 percent to 363 percent of body weight and CP 1RM ranged from 25 percent to 103 percent of body weight. Multiple regression analyses predicting LP 1RM showed that body mass index and long jump were significant ($R^2 = 44.4$ percent with age and gender not significant) and body mass index and vertical jump were significant ($R^2 = 40.8$ percent with age and gender not significant). Multiple regression analyses predicting CP 1RM showed that body mass index and handgrip strength were significant ($R^2 = 58.6$ percent with age and gender not significant). Age and gender alone accounted for 4.6 percent (not significant) of the variation in LP 1RM and 15.4 percent (significant) in CP 1RM. The results indicated that body mass index, handgrip strength, long jump, and vertical jump relate to 1RM strength in children and therefore may be useful for assessing muscular fitness in youths.

Ortega et al. (2008) determined the levels of several health-related physical fitness components with respect to chronological and biological age (sexual maturation status) in Spanish adolescents ($n = 2859$; 1357 males, 1502 females). Sit and reach, handgrip strength, standing broad jump, bent arm hang, 4×10 m shuttle run, and 20 m shuttle run tests were performed. Percent body fat, fat free mass and leisure-time physical activity were used as confounders. Result showed that muscular fitness was higher in older adolescents than in younger adolescents. Cardio-respiratory fitness was higher in younger compared to older females, as well as in early puberty compared to late puberty. In males, cardio respiratory fitness was higher in younger adolescents, but no differences were observed when it was analyzed according to sexual maturation status.

Schlüssel et al. (2008) presented reference values for handgrip strength of healthy adults (age≥20 years) from a household survey. Data for handgrip strength was obtained from 1122 males and 1928 females with a Jamar mechanical dynamometer in both hands. Results showed that mean values of right and left handgrip strength were 42.8 kg and 40.9 kg for males, and 25.3 kg and 24.0 kg for females, respectively. Handgrip strength increased with age and significantly decreased after 40 and 50 year olds for women and men, respectively. BMI was associated with handgrip strength in both sexes but only underweight male subjects had significantly lower handgrip strength values.

Adedoyin et al. (2009) studied reference values for handgrip strength in healthy Nigerian adults. Seven hundred forty-five (409 male and 336 female) healthy volunteers
from the ages of 20-70 years were selected and handgrip was measured using a Takei Kiki Kogyo handgrip dynamometer. Men exhibited higher handgrip strength than that in women in both dominant and non-dominant hands. These findings suggested that males had significantly higher handgrip strength than females. Handgrip strength decreased with increasing age for both dominant and non-dominant hands.

Castro-Piñero et al. (2009) tested percentile values for muscular strength field tests in Spanish children aged 6 to 17.9 years (1,513 boys and 1,265 girls). The influence of body weight on the muscular strength level across age groups was examined. Explosive strength, upper-body muscular endurance and abdominal muscular endurance were assessed by activities like standing broad jump, vertical jump tests (lower body), push ups, bent arm hang, pull ups tests, sit ups etc. Significantly better scores were observed in boys than in girls in all the studied tests, except in the upper-body muscular endurance tests in the 6 to 7 year old group and in the push ups test in the 8 to 9 year-old group. Underweight and normal weight individuals showed similar strength levels. Both underweight and normal weight children and adolescents had significantly higher performance than their overweight and obese counterparts in the lower-body explosive strength tests and in the push ups test in boys and bent arm hang test in both boys and girls. The overweight and obese groups had worse scores than their underweight and normal weight counterparts, whereas the underweight group had a similar performance to the normal weight group.

Demura and Miyaguchi (2009) examined the reliability of parameters and the muscle power output properties in both genders (15 men and 15 women). Each subject carried out explosive grip tests twice using a simple muscle power measurement device (weight loading method), each time with 20, 30, 40, and 50 percent loads of maximum grip strength by isometric contraction. The reliability of each parameter in all loads was good (interclass correlation coefficient > 0.75) for both genders. The maximum grip strength showed non-significant correlation with all parameters. Peak power values were larger in men than in women for all loads, and the women's values were 44.5-52.2 percent of the men's. A large gender difference was found for 20 percent maximum grip strength. It was concluded that the reliability of muscle power parameters measured by the measurement device was high.
Jürimäe et al. (2009) conducted a study on pre-pubertal children aged between 8 and 11 years (n = 64, 27 boys, 37 girls). Basic anthropometric variables (height, body mass, body mass index, biceps and triceps skinfolds, arm relaxed, arm flexed, forearm and wrist girths, acromiale-radiale, radiale-styliion-radiale and midstyliion-dactyliion length and humerus breadth; five fingers’spans, fingers’lengths and perimeters of the hand), hand anthropometric variables, total body and hand composition, total body and hand bone mineral density and bone mineral content, total body and right-hand fat percentage, fat mass and lean mass were determined. Stepwise multiple regression analysis indicated that the most important predictive value from the basic anthropometric variables was body height. Measured skinfold thicknesses and breadths did not show any relation to handgrip strength in any group. Forearm girths significantly predicted handgrip strength in boys (30.8 percent), girls (43.4 percent) and total group (43.4 percent). Handgrip strength was more dependent on the anthropometric and body composition variables in boys than girls.

Marrodán et al. (2009) provided reference standard of handgrip strength for the Spanish population of both sexes between 6 and 18 years old. The handgrip strength of both hands was taken with a digital adjustable dynamometer on 2125 subjects between the 6 and 18 years (1176 boys and 949 girls). Weight, height, forearm circumference and skinfold thickness, body mass, percentage of fat, muscle and fat forearm areas were estimated. Multiple correlation analysis was applied to establish the relationship between handgrip dynamometric force, body mass index and body composition variables. It was found that handgrip strength increased with age and a significant sexual dimorphism was observed from the age of 12 years. The correlation between hand static force and fat free mass or arm muscle area was stronger than with direct size variables or body mass index.

Werle et al. (2009) determined age and gender-specific reference values for grip and pinch strength in a normal Swiss population with special regard to old and very old subjects as well as to different levels of occupational demand. Hand strength data were collected on 1023 subjects between 18 and 96 years using a Jamar dynamometer and a pinch gauge with standard testing position, protocol and instructions. Results revealed a curvilinear relationship of grip and pinch strength to age and a correlation to height,
weight and significant differences between occupational groups. Hand strength values differed significantly from those of other populations.

Barr *et al.* (2010) examined the relationship of birth weight and arm muscle area at birth and post-natal growth to handgrip strength in Indian children. Grip strength was measured in 574 children aged 9 years, who had detailed anthropometry at birth and every 6-12 months post-natally. At 9 years, the children were found to be short compared with the World Health Organization growth reference. Weight, length and arm muscle area at birth, but not skinfold measurements at birth, were positively related to 9 year grip strength. Grip strength was positively related to 9 year height, body mass index and arm muscle area and to gains in these measurements from birth to 2 years, 2-5 years and 5-9 years (p<0.001 for all). The associations between birth size and grip strength were attenuated but remained statistically significant for arm muscle area after adjusting for 9 year size. Larger overall size and muscle mass at birth was associated with greater muscle strength in childhood, and this was mediated mainly through greater post-natal size. Poorer muscle development in utero was found to be associated with reduced childhood muscle strength.

Chandrasekaran *et al.* (2010) investigated the effect of age, gender and the anthropometric measures on handgrip strength in 229 subjects (115 males and 114 females) with age 23±2 and 21±2 years respectively. Weight, height and handgrip strength were measured using standard techniques. Grip strength showed moderate to high correlation with age (r=0.44, p=0.00), height (r=0.57, p=0.00), weight (r=0.57, p=0.00) and BMI (r=0.29, p=0.00). It was concluded that age, height and weight were the important determinants of the handgrip evaluation.

Cohen *et al.* (2010) examined handgrip strength of 7147 English school children (3773 boys and 3374 girls) aged 10-15.9 years using a portable Takei handgrip dynamometer. Significant increase in handgrip strength was found between every age-group (p<0.001) in boys and girls. Boys were significantly stronger than girls at every age (p<0.001) and the boys' age-related increase was significantly greater than the girls' (p<0.001). Handgrip strength in English children was found to be broadly similar to existing European data.
Gallup et al. (2010) studied the relationship between handgrip strength and measures of aggression and social competition among adolescents. Handgrip strength was measured on 68 male (ages 13-15 years, mean = 14.21 years, S.D. = ±.48) and 70 female (ages 14-16 years, mean = 14.21, S.D. = ±.45) ninth grade high school students from a mid-sized public high school. Aggression and social competition among adolescents was also surveyed. Survey results indicated that the majority of aggressive peer interactions were intra-sexual, with 85.92 percent of males and 73.55 percent of females reporting victimization, and 94.34 percent of males and 75.59 percent of females reporting aggression described the interactions as predominantly with members of the same sex. Correlations were almost exclusive to males, but this was only visible during late adolescence. These findings supported evolutionary hypotheses regarding grip strength in male-male competition suggesting that similar to measures of testosterone, handgrip strength is a measure predictive of social behavior in older adolescent males.

Li et al. (2010) conducted a study to analyze the correlations between anthropometric data and maximal grip strength in order to establish a simple model to predict normal maximal grip strength. Randomized bilateral measurement of maximal grip strength was performed on a homogeneous population of 100 subjects. Maximal grip strength was measured according to a standardized protocol with three dynamometers (Jamar, Myogrip and Martin Vigorimeter) for both dominant and non-dominant sides. Height, weight, hand, wrist and forearm circumference; hand and palm length were also measured. Findings of the study suggested that hand circumference had the strongest correlation with maximal grip strength for all three dynamometers and for both hands (0.789 and 0.782 for Jamar; 0.829 and 0.824 for Myogrip; 0.663 and 0.730 for Vigorimeter).

Sallinen et al. (2010) conducted a study to determine optimal handgrip strength cut points for likelihood of mobility limitation in older people and to study whether these cut points differ according to body mass index (BMI). 1,084 men and 1,562 women aged 55 and older were studied with complete data on anthropometry, handgrip strength and self-reported mobility. Results showed that overall handgrip strength cut points for likelihood of mobility limitation were 37 kg for men and 21 kg for women. The effect of the interaction between handgrip strength and BMI on mobility limitation was significant.
in men (p =.02), but no such interaction was observed in women (p =.16). In men, the
most-optimal cutoff points were 33 kg for normal-weight men, 39 kg for overweight men
and 40 kg for obese men. In women, a BMI specific handgrip strength cutoff value was
not markedly more accurate than the overall cutoff value. They concluded that the
handgrip strength test is a useful tool to identify persons at risk of mobility limitation.

Taekema et al. (2010) assessed if handgrip strength predicted changes in
functional, psychological and social health among older population. Handgrip strength
was measured with a handgrip strength dynamometer on a total of 555 subjects, aged 85
years at baseline. Functional, psychological and social health was assessed annually. It
was found that at age 85, lower handgrip strength correlated with poorer scores in
functional, psychological and social health domains (all, p<0.001), while the lower
baseline handgrip strength predicted an accelerated decline in activities of daily living
and cognition (both, p ≤ 0.001), but not in social health (p > 0.30). Poor handgrip strength
predicted accelerated dependency in activities of daily and cognitive decline in older
population.

Wind et al. (2010) examined the relation of grip strength to the total muscle
strength in children, adolescents, and young adults for providing reference charts for grip
strength. 384 healthy Dutch children, adolescents, and young adults at the age of 8 to
20 years were selected and their isometric muscle strength of four muscle groups
(shoulder abductors, grip strength, hip flexors, and ankle dorsiflexors) was measured with
a handheld dynamometer. Total muscle strength was a summing up of shoulder
abductors, hip flexors, and ankle dorsiflexors. Grip strength strongly correlated with total
muscle strength, with correlation coefficients between 0.736 and 0.890 (p < 0.01). However, the correlation was weaker when controlled for weight (0.485-0.564, p < 0.01).
Grip strength was related to total muscle strength. This indicated, in the clinical setting,
that grip strength can be used as a tool to have a rapid indication of someone’s general
muscle strength.

Massy-Westropp et al. (2011) provided normative data for handgrip strength in a
community-based Australian population and investigated the relationship between body
mass index and handgrip strength. They also compared Australian data with international
handgrip strength norms. Handgrip strength measurement was done on 1366 men and
1312 women participants. Results showed a weak correlation of higher handgrip strength to higher BMI in adults under the age of 30 and over the age of 70 years, but inverse relation to higher BMI between these ages. Australian norms from this sample had amongst the lowest of the handgrip strength of the internationally published norms, except those from underweight populations.

Ortega et al. (2011) investigated gender and age-specific physical fitness levels in European adolescents. A sample of 3428 adolescents (1845 girls) aged 12.5-17.49 years from 10 European cities was selected and their physical characteristics like muscular fitness, speed/ agility, flexibility and cardio-respiratory fitness were evaluated using nine different fitness tests like handgrip, bent arm hang, standing long jump, Bosco jumps (squat jump, counter movement jump and Abalakov jump), 4×10-m shuttle run, backsaver sit and reach and 20-m shuttle run tests. Increased physical fitness with an increase in age was observed in boys, whereas the fitness levels in the girls were more stable across ages.

Ribom et al. (2011) determined the reference values for muscle strength tests and functional tests in 999 subjects aged 70-80 years. Muscle strength and functional performance was tested by timed-stands test, 6 m and 20 cm narrow walk tests and Jamar handgrip strength test. It was found that with increasing age, there was a 10-18 percent successively decline in performance throughout the entire age span. The decline in the test values with increasing age, infered the use of age-specific normative data when using these tests both in clinical and research settings.

Samuel et al. (2012) aimed to characterize the relative changes in handgrip and lower limb muscle strength with aging by expressing them as a ratio. They selected thirty-eight healthy volunteers aged 20-82 years who performed maximal voluntary contractions of quadriceps and handgrip using a custom-built transducer and a Jamar dynamometer respectively. It was found that the grip-quadriceps ratio for young adults was similar in males and females (0.75), indicating knee extensor force exceeded grip force by approximately 25 percent. Ratios were increased in older adults (p = 0.05) and strength of the two muscle groups was approximately equal (1.1). Pearson’s correlation coefficients for grip against quadriceps strength were r = 0.63 (young males), r = 0.83 (young females), r = 0.35 (older males) and r = 0.05 (older females). It was concluded
that the ratio used demonstrated clear differences between the age groups. The reduced muscle strength with increasing age was expected but the higher grip/quadriceps strength ratios quantified a greater loss of quadriceps than grip strength with aging.

2.2 Handgrip Strength in Patients with Different Diseases

Humphreys et al. (2002) evaluated the efficacy of muscle strength to predict functional derangement and detect early changes in nutrition status in 50 hospitalized patients (26 men and 24 women) with a median hospital stay of 10 days. Subjective Global Assessment was associated with anthropometric data, handgrip dynamometry, and serum levels of total proteins. Results showed that the patients in whom functional status declined during hospital stay, on admission had lower left handgrip strength, a worse Subjective Global Assessment classification, were older, and had lower fat mass. No association between caloric balance during hospital stay and changes in muscle strength was observed.

Van Lier and Payette (2003) determined anthropometric and personal factors that affected handgrip strength in a group of free-living elderly at risk of malnutrition. The factors associated with handgrip strength were entered in a multiple linear regression model (n = 166) to identify the independent prediction factors. Reliability of the model was verified with a sub-group of 65 subjects randomly selected from the initial sample. It was found that both groups were statistically similar regarding all factors studied. Bivariate analyses showed that handgrip strength was associated with sex, age, pain, hand circumference, and waist-hip ratio. Multiple linear regression analysis identified age, pain, and sex as independent determinants of handgrip strength ($R^2 = 0.16$). Hence it was concluded that women had smaller handgrip strength than men and that handgrip strength decreased with increasing age and the presence of pain.

Ford et al. (2008) measured the handgrip strength as a part of the 5 year neuro-developmental assessment of 24 very low birth weight (VLBW) and 18 normal birth weight (NBW) children. It was observed that handgrip strength was significantly lower in the VLBW children for left and right hands tested individually and for both hands used concurrently. Increasing handgrip strength was significantly related to 5 year weight percentiles and to being in the NBW group. More of the VLBW children weighed less
than the 10th percentile. After adjusting for the 5 year weight percentile, the handgrip strength of VLBW children was still significantly lower than that for NBW children.

Jakobsen et al. (2010) investigated the extent to which handgrip strength, endurance, and work was related to physical function as measured by mobility and physical activity in 92 healthy volunteers (45 percent men, mean age 30 years) and 45 patients (56 percent men, mean age 55 years). The relations between handgrip strength, mobility, physical activity and quality of life in patients were investigated. It was observed that there was a correlation between handgrip strength and mobility in healthy subjects ($r = -0.31$, $p = 0.0028$) and patients ($r = -0.59$, $p < 0.0001$). Further, handgrip strength and mobility were related to physical and mental component summary scores of quality of life in patients. There was also a relation between handgrip strength and physical activity in healthy female subjects and male patients. Handgrip endurance and work were not found to be valid measurements of mobility and physical activity in healthy subjects or of quality of life in patients.

Marin et al. (2010) evaluated 117 physically active postmenopausal women (67.8+/-7.0 years) who performed neuromotor physical tests (strength, balance, and mobility). Body composition (lean mass, fat mass, and percent fat) and bone mineral density of lumbar spine, femoral neck, and total body were measured by dual-energy X-ray absorptiometry. Following the World Health Organization criteria, osteoporosis was found in at least 1 analyzed site in 33 volunteers (28.2 percent): 30 (25.6 percent) in lumbar spine and 9 (7.7 percent) in femoral neck. It was observed that body weight and lean mass were related to all bone mineral density sites, whereas fat mass was weakly related to the femoral neck bone mineral density. Percent fat did not correlate with any bone mineral density site. Of all the physical tests, the handgrip strength was most importantly related to lumbar spine, femoral neck, and total body ($r=0.49$, $p<0.001$; $r=0.56$, $p<0.001$; and $r=0.52$, $p<0.001$, respectively). Results suggested that strategies aiming to improve muscle strength and lean mass contribute to the bone health of physically active postmenopausal women.

Norman et al. (2011) reviewed the prognostic relevance of grip strength in various clinical and epidemiologic settings and investigated its suitability as marker of nutritional status in cross-sectional as well as intervention studies. In patients, impaired
grip strength acted an indicator of increased postoperative complications, increased length of hospitalization, higher re-hospitalisation rate and decreased physical status. In elderly in particular, loss of grip strength implied the loss of independence. Epidemiological studies had moreover demonstrated that low grip strength in healthy adults predicted increased risk of functional limitations and disability in higher age as well as all-cause mortality.

Aparicio et al. (2011) correlated handgrip strength with the presence and absence of fibromyalgia and its severity in women. Women with fibromyalgia (mean age ± SD, n=81; 50.0±7 years) and healthy women (mean age ± SD, n=44; 47.7±6 years) were selected for the study. Handgrip strength was measured in both hands by a maximal isometric test using a hand dynamometer. Patients were classed as having moderate fibromyalgia on the basis of fibromyalgia Impact Questionnaire (FIQ). It was observed that handgrip strength levels were lower in patients with fibromyalgia than healthy women and in women with severe fibromyalgia (FIQ≥70) compared with those with moderate fibromyalgia (FIQ<70). In the fibromyalgia group, handgrip strength 16.9 kg or less was associated with 5.3 times higher odds for having severe fibromyalgia.

Bragagnolo et al. (2011) investigated whether handgrip strength and adductor pollicis muscle (TAPM) thickness were reliable indicators of postoperative outcome in patients undergoing major abdominal operations. A prospective cohort study was conducted on 90 patients who underwent major digestive tract surgery. All patients were subjected to anthropometric measurements and subjective global assessment. Both handgrip strength and TAPM were analyzed as potential risk factors for postoperative outcome. Results showed significant correlation of TAPM with all anthropometric measurements (p < 0.001). Multivariate linear regression analysis indicated that both handgrip strength and TAPM were significantly greater in male, nourished, and younger patients. Abnormal TAPM was associated with an increased number of complications. The length of postoperative hospital stay was greater in patients with abnormal handgrip strength (p = 0.02). It was concluded that both the TAPM and handgrip strength were excellent tools for evaluating nutritional status and predicting the outcome of surgical patients.
Stenholm et al. (2012) examined long-term changes in handgrip strength and the factors predicting handgrip strength decline. 963 men and women aged 30 to 73 years at baseline were selected and their handgrip strength was measured using a handheld dynamometer at baseline and over 22 years of follow-up. Results showed that factors like midlife physically strenuous work, excess body weight, smoking, cardiovascular disease, hypertension, diabetes mellitus, and asthma predicted muscle strength decline over 22 years of follow-up (p< 0.05 for all). In addition, pronounced weight loss, becoming physically sedentary, persistent smoking, incident coronary heart disease, other cardiovascular disease, diabetes mellitus, chronic bronchitis, chronic back syndrome, long-lasting cardiovascular disease, hypertension, and asthma were also associated with accelerated handgrip strength decline (p< 0.05 for all). Lifestyle and physical health earlier in life determined rate of muscle strength decline in old age.

Haverkort et al. (2012) evaluated the accuracy of four algorithms in diagnosing malnutrition by measuring handgrip strength on 504 preoperative outpatients. They were tested for malnutrition on the basis of percentage involuntary weight loss and body mass index. Diagnostic characteristics of the handgrip strength algorithms (Álvares-da-Silva, Klidjian, Matos, Webb) were expressed by sensitivity, specificity, positive and negative predictive value, false positive and negative rate. The prevalence of malnutrition was 5.8 percent, 6 out of 29 malnourished patients were falsely identified as well-nourished (false positive rate 21 percent, 95 percent CI 9 percent–38 percent). In contrast, this algorithm showed the lowest positive predictive value (8 percent, 95 percent CI 5 percent–13 percent). Matos presented the highest positive predictive value; the post-test probability increased to 13 percent (95 percent CI 8 percent–20 percent). The 1-minus negative predictive value ranged between 3 percent and 5 percent for all algorithms. Hence, none of the algorithms derived from handgrip strength measurements was found to have a diagnostic accuracy.

2.3 Handgrip Strength in Sport Persons

Morris et al. (1989) outlined the EMG activity of the wrist and forearm musculature during the tennis serve and ground strokes. They reported high levels of muscular activity during the acceleration phase of the ground stroke as well as during late
cocking and acceleration of the service motion in the wrist flexors and extensors and the forearm pronators.

Pugh *et al.* (2003) studied upper and lower body strength in relation to ball speed during a serve by male collegiate tennis players. The relation of leg, shoulder, and grip strength to ball speed in the tennis serve was investigated in 15 collegiate male tennis players. Their leg and shoulder strength was measured using a Lido Active Isokinetic dynamometer, grip strength with a handgrip dynamometer, and ball speed with a radar gun. Regression analysis showed no significant (p>0.05) relationship among the strength variables and ball speed.

Ducher *et al.* (2005) investigated the effects of long-term tennis playing on the relationship between lean tissue mass and bone mineral content in the forearms. Lean tissue mass, bone area, bone mineral content, bone mineral density and grip strength of fifty-two tennis players were measured at the forearms from a DXA whole-body scan. A marked side-to-side difference (p < 0.001) was found in favor of the dominant forearm in all parameters. Bone area and bone mineral content correlated with grip strength on both sides (r = 0.81-0.84, p < 0.001). The correlations were still significant after adjusting for whole-body bone mineral content, body height, or forearm length. This result supported the fact that the muscles have putative role in the mechanical loading on bones. Also, forearm bone mineral content adjusted to lean tissue mass or grip strength was higher on the dominant side, suggesting that tennis playing exerts a direct effect on bone.

Ellenbecker *et al.* (2006) determined whether there were laterality differences in wrist extension/flexion (E/F) and forearm supination / pronation strength in elite female tennis players. They conducted a study on 32 elite female tennis players (age 12 to 16 years) with no history of upper extremity injury and carried out bilateral isokinetic testing. Significantly greater (p<0.01) dominant arm wrist E/F and forearm pronation strength and significantly less (p<0.01) dominant side forearm supination strength were measured at both testing speeds. Greater dominant arm wrist E/F and forearm pronation strength was common and normal in young elite level female tennis players.

Kovacks *et al.* (2007) investigated the impact of a 5 week off-campus structured, yet unsupervised; break from regular training in top collegiate tennis players. A nationally ranked collegiate NCAA Division I male tennis team (n=8) performed a test
battery in December and again in January after a 5 week period of recommended, yet unsupervised, training. The tests performed were grip strength and range of motion (ROM) measures (goniometer) of the shoulder, hip, hamstring and quadriceps, 5, 10 and 20 m sprints and other variables. Results suggested significant reductions in speed, power and aerobic capacity in competitive tennis players, likely owing to poor compliance with the prescribed training regimen after a 5 week interruption of normal training.

Lucki et al. (2007) studied the phenotypic plasticity and functional asymmetry in response to grip forces exerted by intercollegiate tennis players. Compressive grip performance was measured for division 1 collegiate tennis players (24 female, 24 males) and non-athlete college students (18 females, 17 males) during three experiments: single repetition maximum voluntary contraction, 30 consecutive repetitions, and a 30 seconds static hold. Tennis had a significant asymmetry in both forearm circumference and grip strength. The dominant hand of female tennis players produced 25 percent more force than the opposite hand, while the difference between hands of male tennis players was 18 percent. However, endurance over 30 repetitions and during the 30 seconds hold did not significantly differ between the limbs of tennis players. No significant asymmetry in forearm measurements, grip strength, or endurance was detected between the limbs of non-athletes. Tennis players had increased muscle mass and strength of the dominant limb.

Girard and Millet (2009) examined the relationships between speed, explosive power, leg stiffness, and muscular strength of upper and lower limbs; and how much these physical qualities related to tournament play performance in a group of competitive teenage tennis players. A total of 12 male tennis players aged 13.6 +/- 1.4 years performed a series of physical tests: a 5-m, 10-m, and 20-m sprint; squat jump; countermovement jump; drop jump; multi-rebound jumps; maximum voluntary contraction of isometric grip strength; and plantar flexion of the dominant and non-dominant side. Speed, vertical power abilities, and maximal strength in the dominant side ($r = -0.67$ and $-0.73$ for handgrip and plantar flexor, respectively) were significantly correlated with tennis performance. However, strength in the non-dominant side ($r = -0.29$ and $-0.42$ for handgrip and plantar flexor) and leg stiffness were not correlated with
the performance ranking of the players. It was concluded that physical attributes of players had a strong influence on tennis performance in this age group.

Pereira et al. (2011) compared the handgrip strength using the European Test of Physical Fitness Handbook (Eurofit) and American Society of Hand Therapists (ASHT) technique between dominant/non-dominant hands, and between different ages of juvenile tennis player athletes (n=137 males and 45 females; aged 8-18 years). In order to assess handgrip strength following the Eurofit and ASHT recommendations, a Jamar dynamometer was used. There was no difference in handgrip strength between Eurofit and ASHT recommendations regardless of sex. The best curve to describe the regression of handgrip strength and age for both genders was a sigmoid function. Males presented a higher slope at 11 years and females had a higher slope at 10 years. Moreover, in male athletes dominant handgrip strength presented higher values than non-dominant handgrip strength beginning at 14 years. However, for the females the asymmetry in handgrip strength did not occur for any age until 18 years.

Kannus et al. (1995) studied the effect of biological age on the difference in bone mineral content between the playing and non-playing arms in female tennis and squash players. They compared the differences in bone mineral content in playing and non-playing (dominant to non-dominant) arms (proximal humerus, humeral shaft, radial shaft, and distal radius) in players and controls and among six groups of players. Various anthropometric parameters such as height, weight, upper arm circumference, handgrip strength, maximal isometric strength of upper extremities, and bone mineral density were measured. Compared with controls, the players had a significantly (p< 0.001) larger side to side difference in every measured site. The dominant to non-dominant side difference in upper arm and forearm circumference and muscle strength was significantly greater in players than in controls. It was concluded that bones of the playing extremity clearly benefit from active tennis and squash training, which increased their mineral mass.

Brylinskyl et al. (1992) investigated the use of a weighted softball in training to improve throwing velocity, wrist strength and handgrip of novice softball pitchers. 37 female college students were assigned to a weighted ball or regulation ball group. Both groups completed the same six-week training program, incorporating lob pitching and distance throwing routines. Findings provided little support for the weighted ball.
Giardina et al. (1997) studied the relationship of grip strength and forearm size to softball bat velocity in 18 female college varsity softball players (age = 20.3 years; weight = 162 lbs) with a minimum of five years of competitive experience. Three right and three left isometric grip strength measurements were taken on each subject using a Jamar hand dynamometer. Results indicated no significant relationships between bat velocity and any size or strength measurements, but the relationship between bilateral measurements were positive and significant, indicating symmetry in size and strength.

Pugh et al. (2001) observed the relation of legs, arms, shoulders, and grip strength with underhand pitching speed in 16 experienced underhand pitchers and 16 inexperienced women with no softball experience (control group). Their leg and arm strength was measured using hydra fitness exercise machine and grip strength with a handgrip dynamometer. Underhand throwing speed was measured with a radar gun. Regression analysis showed arm and grip strength correlated with throwing speed (p≤.05) for the experienced group and arm strength was the only correlate of throwing speed (p≤.05) for the inexperienced control group. There was a significant difference between the two groups on all measures of strength and ball speed in favour of the experienced group.

Hughes et al. (2004) studied effect of grip strength and grip strengthening exercises on instantaneous bat velocity of collegiate baseball players. The study included 23 male members (age = 19.7 +/- 1.3 years, height = 182.5 +/- 5.9 cm, weight = 85.4 +/- 15.5 kg, experience = 14.4 +/- 1.7 years) of a varsity baseball team at a national collegiate athletic association division 2 school. Subjects were randomly divided into experimental group and control group. For 6 weeks, both groups participated in their usual baseball practice sessions. Pre-test and post-test correlations between grip strength and bat velocity revealed no significant relationship between grip strength and bat velocity (pre-test r = 0.054, p = 0.807; post-test r = 0.315, p = 0.145). The findings of the study suggested that grip strength and bat velocity were not significantly related.

Hoffman et al. (2009) compared anthropometric and performance variables in professional baseball players and examined the relationship between those variables and baseball specific performance (i.e., home runs, total bases, slugging percentage, and stolen bases). During a 2-year period, 343 professional baseball players were assessed for
height, weight, body composition, grip strength, vertical jump power, 10 yard sprint speed, and agility. Results indicated that both anthropometric and performance variables differed between players of different levels of competition in professional baseball. Agility, speed, and lower-body power appeared to provide the greatest predictive power of baseball-specific performance.

Hasan et al. (2007) carried out a study on anthropometric measurements of 60 female Asian handball players to identify any differences between countries and between playing positions. These players were selected from teams of China, Japan, Kazakhstan and South Korea. Measurements included height, mass, skinfold thicknesses, percent body fat and muscle mass. Profiles were compared between 4 nations and 4 positional roles by means of ANOVA. Overall, mean (SD) values were 1.708 (0.068) m, 64.6 (7.7) kg, 20.8 percent (4.4 percent), 39.6 percent (5.2 percent) for stature, mass, percent body fat and percent muscle mass, respectively. There were small non-significant differences (p>0.05) between players from different countries without any influence of playing positions. Players from Japan were shortest, lightest and lowest in adiposity. The Chinese players were tallest and had the greatest muscle mass. The female international handball players differed in some respects in anthropometric characteristics according to their country of origin. The Asian players were found to be relatively homogeneous across the different positions.

Visnapuu et al. (2007) investigated the influence of general body and hand-specific anthropometric dimensions on handgrip strength in boys participating in handball and basketball training. Results indicated that anthropometric parameters, finger lengths and perimeters of the hand showed significant correlation with the maximal handgrip strength.

Bayios et al. (2006) carried out a study to determine the anthropometric profile, body composition and somatotype of 518 elite Greek female basketball, volleyball and handball players, to compare the mean scores among sports and to detect possible differences in relation to competition level. Twelve anthropometric measures and somatotype components were obtained. Results concluded 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).

Barut et al. (2008) measured various hand anthropometric measurements and handgrip strength on 145 basketball players, 133 volleyball players and 96 handball players aged between 9-18 years. Eight parameters were evaluated for each hand. Statistically significant differences were observed for right and left hand width, right finger index, right hand length/height, left hand length/height values between basketball, handball and volleyball players. These differences were observed due to differences between basketball and handball players. Statistically significant differences were found in right and left hand width, right and left third finger length, right and left handgrip strength values in female handball players than their male counterparts. These findings suggested that different sports could constitute different effects on hand anthropometric measurements and grip strength.

Koley et al. (2010) evaluated the arm anthropometric profile and correlated various arm anthropometric characteristics and their association with handgrip strength in 60 Indian inter-university basketball players (35 males and 25 females, aged 18-25 years). Three anthropometric characteristics, nine arm anthropometric characteristics, and grip strength of both right and left hand were measured. An adequate number of control subjects were also selected. The results indicated statistically significant (p ≤ 0.05-0.01) differences between the male basketball players and the controls in height, right handgrip strength, upper arm, forearm and total arm length, whereas no significant differences were found between the female basketball players and the controls. Highly significant (p ≤ 0.01) sex differences were found in the basketball players in almost all the variables studied (except body mass index and arm fat area). Significant positive correlations were noted among the arm anthropometric characteristics studied (except arm fat area and arm fat index), and with right and left handgrip strength.
Cortis et al. (2011) investigated whether basketball players were able to maintain strength (handgrip), jump (counter-movement jump), sprint (10 m and 10 m bouncing the ball), and inter-limb coordination performances at the end of their game. Ten young (age 15.7 ± 0.2 years) male basketball players volunteered for the study. During the friendly game, heart rate (HR), rate of perceived exertion (RPE), and rate of muscle pain (RMP) were assessed to evaluate the exercise intensity. Overall, players spent 80 percent of the time playing at intensities higher than 85 percent HR\textsubscript{max}. At the end of the game, players reported high (p<0.05) RPE (15.7 ± 2.4) and RMP (5.2 ± 2.3) values; decreased (p < 0.05) sprint capabilities; increased (p<0.05) inter-limb coordination at 180 bpm and maintained jump, handgrip, and coordinative performances at lower frequencies of executions. These findings indicated that the heavy load of the game exerted beneficial effects on the efficiency of executive and attentive control functions involved in complex motor behaviors.

Karalejic et al. (2011) determined five longitudinal measures, two transversal measures, body mass, four circumferences, six skinfolds and 3 derived variables: Body mass index, sitting height/stature ratio and sum of skinfolds in sample of 118 young basketball players, 54 of 14 (±0.5) year old and 64 of 12(±0.5) year old. The study was undertaken to describe the anthropometric characteristics and technical skills in children aged 12 and 14 years taking part in competitive basketball, to compare the mean scores between these two groups and to detect the relationship between anthropometric characteristics and basketball skills. Results indicated significantly lower values of sum of skinfolds and higher values of most of anthropometric variables in 14 year old players as compared to 12 year old, except in sitting height/stature ratio and body mass index which were similar. The correlation between certain field tests and some anthropometric parameters indicated that some anthropometric measures had moderately negative influence on test results in technical skills in 14 year old players.

Gerodimos (2012) examined the reliability of handgrip strength in basketball players from childhood to adulthood using the Jamar hand dynamometer. Male basketball players (n = 90) were assigned into three groups: pre-pubertal (9.8 ± 0.7 years), adolescents (14.4 ± 0.6 years), and adults (26.1 ± 5.6 years). Each participant performed three maximal isometric contractions on each hand in two occasions, one day apart. Intra-
class correlation coefficient (ICC), standard error of measurement and 95 percent limits of agreement were calculated. The test-retest reliability was high for both preferred (ICC = 0.94-0.98) and non-preferred (ICC = 0.96-0.98) hands, without differences in reliability among age-groups. Significant age related increase (p<0.05) was observed in absolute and relative handgrip strength irrespective of hand preference. The results indicated that maximum handgrip strength could be measured reliably, using the Jamar hand dynamometer, in basketball players from childhood to adulthood.

Koley and Kaur (2011) correlated some hand and arm anthropometric variables in 101 randomly selected Indian inter-university female volleyball players, aged 18-25 years (mean age 20.52 ± 1.40) from six Indian universities. Various variables like height, weight, body mass index, right and left hand width and length, upper arm length, lower arm length, upper extremity length, upper arm circumference and dominant right and non-dominant handgrip strength were measured. Indian female volleyball players showed higher mean values in eleven variables and lesser mean values in two variables than their control counterparts, showing significant differences (p<0.032-0.001) in height (t=2.63), weight (t=8.66), left hand width (t=2.10), left and right hand length (t=9.99 and 10.40 respectively), right upper arm length (t=8.48), right forearm length (t=5.41), dominant (right) and non-dominant (left) handgrip strength (t=9.37 and 6.76 respectively). In female volleyball players, dominant handgrip strength had significantly positive correlations (p≤0.01) with all the variables studied.

Koley et al. (2012) correlated three anthropometric characteristics, four body composition parameters, two physical and two physiological characteristics on randomly selected 63 inter-university volleyball players (38 males and 25 females) aged 18-25 years from six Indian universities. An adequate number of controls (n = 102, 52 males and 50 females) were also taken. One way analysis of variance showed significant (p ≤0.004-0.001) differences in all the variables between volleyball players and controls. In volleyball players, significantly positive correlations were found between right and left handgrip strength and all the variables studied except percent body fat (where the correlations were significantly negative).

Aouadi et al. (2012) carried out a study to examine the association between physical and anthropometric profiles and vertical jump performance in 33 elite volleyball
Review of Literature

players (21±1 years, 76.9±5.2kg, 186.5±5cm). Several anthropometric measurements (body mass, stature, body mass index, and lower limb length and sitting height) together with jumping height, anaerobic power of counter movement jump with arm swing (CMJ\textsubscript{arm}) were obtained from all subjects. It was found that anaerobic power was significantly higher (p≤0.05) in the tallest players relative to their shorter counterparts. A significant relationship was observed between CMJ\textsubscript{arm} and lower limb length (r\textsuperscript{2}=0.69; p<0.001) and between the lower limb length and anaerobic power obtained with CMJ\textsubscript{arm} (r\textsuperscript{2}=0.57; p<0.01). While significantly correlated (p≤0.05) with CMJ\textsubscript{arm} performance, stature, lower limb length/stature and sitting height/stature ratios were not significant (p>0.05) predictors of CMJ\textsubscript{arm} performance. It was concluded that lower limb length was correlated with CMJ\textsubscript{arm} in elite male volleyball players. The players with longer lower limbs had the better vertical jump performances and higher anaerobic power.

Scott (1991) carried out anthropometric measurements on hockey players. The players supported lean body build with a stature of 176.3 cm and mass of 75.2 kg and were identified as ecto-mesomorphic. The lean build of the subjects was also evident with a fairly low percentage body fat (11.1 percent) and a relatively high RPI of 41.77. Functional arm length did not appear to have any correlation with hockey playing ability but the grip strength, in both right (54.0 kg) and left (53.1 kg) measures in players was above that of norms for male adults and there was no significant difference between left and right grip strength. The leg strength of the players was good enough with very little variability amongst the players but the hand flexibility (sit and reach mean 9.7) was poor and results indicated a wide range of variability in the sample group tested.

Wassmer and Mookerjee (2002) investigated elite U.S. women's collegiate field female hockey players (37 elite, female collegiate field hockey players (8 backs, 13 forwards, 4 goalkeepers, 8 midfield players and 4 wings) for various anthropometric measurements. Like their male counterparts, they did not show any significant (p>0.05) correlations (r = 0.03 to -0.13) between right and left grip strength and the sport-specific test scores but significant (p<0.05) relationships were found between power and pushing accuracy, as well as between the 50 yard dash and coordination test, pushing power and pushing accuracy. Although the goalkeepers were significantly (p<0.05) heavier and had a higher percent body fat, there were no significant differences (p>0.05) between any of
the player positions in height, limb length, 50-yard dash time, predicted VO$_2$ max, grip strength, agility, or in the field hockey specific tests.

Wu et al. (2003) examined the interaction of players’ skill level, body strength, and sticks of various construction and stiffness on the performance of the slap and wrist shots in ice hockey. Twenty male and twenty female hockey players were selected for the study and ten of each gender group were considered skilled and ten unskilled. In addition to general strength tests, each subject performed the slap and wrist shots with three stick shafts of different construction and stiffness. Shot mechanics were evaluated by simultaneously recording ground reaction forces from a force plate, stick movement and bending from high speed filming and peak puck velocity from a radar gun. Significant differences were observed between skilled and unskilled players, and no similar significant differences were observed in bench press, grip strength, peak attacking angle, and hand placement. The skilled and unskilled groups had similar physical strength characteristics, thus performance differences were attributed to technique difference. The player’s height, weight, bench press, and grip strength variables were positively correlated to the velocity.

Mermier et al. (2000) selected forty four climbers (24 men, 20 women) of various skill levels and years of experience (0.10–44 years). Various anthropometric variables such as height, weight etc., demographic (self-reported climbing rating, years of climbing experience, weekly hours of training), and physiological (knee and shoulder extension, knee flexion, grip, and finger pincer strength, bent arm hang, grip endurance, hip and shoulder flexibility, and upper and lower body anaerobic power) variables were measured and combined into components using a principal components analysis procedure. The results of the multiple regression procedure indicated that the training component uniquely explained 58.9 percent of the total variance in climbing performance while the anthropometric and flexibility components explained only 0.3 percent and 1.8 percent of the total variance in climbing performance respectively.

Grant et al. (2001) reported a comparison of the anthropometric, strength, endurance, and flexibility characteristics of female elite and recreational climbers and non-climbers. The aim of the study was to compare those characteristics in three groups of females; Group 1 comprised of 10 elite climbers (aged 31.3 +/- 5.0 years) who had led
to a standard hard very severe; group 2 consisted of 10 recreational climbers (aged 24.1 +/- 4.0 years) who had led to severe; and group 3 comprised of 10 physically active individuals (aged 28.5 +/- 5.0 years) who had not previously rock-climbed. The tests included finger strength (grip strength, finger strength measured on climbing-specific apparatus), flexibility, bent arm hang and pull-ups. Regression procedures were used to examine the influence of body mass, leg length, height and age. For finger strength, the elite climbers recorded considerably higher values (p < 0.05) than the recreational climbers and non-climbers. For grip strength of the right hand, the elite climbers recorded significantly higher values than the recreational climbers only (elite 338 +/- 12 N, recreational 289 +/- 10 N, non-climbers 307 +/- 11 N). The results suggested that elite climbers had greater finger strength than recreational climbers and non-climbers.

Watts et al. (2003) compared general anthropometric characteristics of junior US competitive rock climbers with elite adult climbers. Ninety subjects were selected and the anthropometric variables, including height, mass, body mass index, arm span, biiliocristal and biacromial breadths, skinfold thickness at nine anatomical sites, forearm and hand volumes, and handgrip strength were measured. A control group (n = 45) of non-climbing children and youths underwent similar procedures. Young competitive climbers showed similar general anthropometric characteristics to elite adult climbers. These included relatively small stature, low body mass, low sums of skinfolds, and high handgrip to mass ratio. Relative to age matched athletic non-climbers, climbers appeared to be more linear in body type with narrow shoulders relative to hips. Differences in body composition existed between climbers and non-climbing athletes despite similar body mass index values.

Mitchell et al. (2011) investigated the relationship between anthropometric characteristics of indoor rock climbers and top roped climbing performance. 10 male (age 20.7 years +/- 3.0, height 176.4cm +/- 8.8, mass 67.7kg +/- 9.6) and 10 female (age 23.2 years +/- 3.8, height 165.3cm +/- 5.2, mass 56.0kg +/- 5.7) advanced level sports climbers were selected for the study. Various anthropometric variables like height, arm span, mass, body mass index, chest, axilla, triceps, subscapular, thigh, suprailliac and abdominal skinfolds, dominant hand pinch, crimp and handgrip strength were measured. It was reported that the female climbers exhibited significantly greater skinfold measurements.
than the males at the triceps, thigh and in the sum of skinfolds. The females also had significantly greater estimated body fat percent than the males (p = 0.001). Males exhibited significantly greater arm span, ape index, pinch grip, crimp grip and handgrip ratios as compared to females. Pearson product-moment correlation coefficients showed a strong, negative correlation between male top-rope climb time and pinch grip (r = -0.937, p = 0.001), crimp grip (r = -0.795, p = 0.006) and handgrip ratios (r = -0.962, p = 0.001). A strong negative correlation was also found between female top-rope climb time and pinch grip (r = -0.774, p = 0.009), crimp grip (r = -0.870, p = 0.001) and handgrip ratios (r = -0.875, p = 0.001). No significant differences were found between male and female top-rope climb times (p>0.05). The results suggested that despite having similar BMI, male and female climbers had dissimilar body composition, with females exhibiting greater estimated body fat percent, triceps and thigh skinfolds and sum of skinfolds.

Guidetti et al. (2002) conducted a study on eight elite Italian amateur boxers and suggested that physical fitness as indicated by individual anaerobic threshold and maximal oxygen consumption and upper-body muscular strength as indicated by handgrip strength related to boxing performance. The body fat percentage, upper arm and forearm muscle cross-sectional areas, grip strength measures and a maximal treadmill test to assess oxygen consumption (VO₂), blood lactate and heart rate at maximal effort, at individual anaerobic threshold, and at individual ventilatory threshold were measured. A Spearman rho correlation analysis revealed that the VO₂ at individual anaerobic threshold (r=0.91) and the handgrip strength (r=0.87) were highly related (p<0.01) to boxing competition ranking. VO₂max (r=0.81) and wrist girth (r=0.78) were moderately (p<0.05) related.

Khanna and Manna (2006) conducted a study on the morphological, physiological and biochemical characteristics of Indian national boxers to assess the cardiovascular adaptation to graded exercise and actual boxing round. Two studies were conducted and in the first study (n = 60, 30 junior boxers below 19 years and 30 senior boxers 20-25 years), different morphological, physiological and biochemical parameters were measured, while in the second study (light weight category <54 kg, n = 7; medium weight category <64 kg, n = 7 and medium heavy weight category <75 kg, n = 7) cardiovascular responses were studied during graded exercise protocol and actual boxing bouts. Results
showed that senior boxers exhibited significantly higher (p<0.05) stature, body mass, LBM, body fat and strength of back and grip, maximal heart rates and recovery heart rates (p<0.05) than junior boxers and they also possessed mesomorphic body conformation. Junior boxers possessed ectomorphic body conformation and showed significantly lower (p<0.05) aerobic capacity and anaerobic power as compared to seniors. The age and level of training in boxing showed significant effect on aerobic, anaerobic component.

Meyers et al. (2000) conducted a study on 24 collegiate female equestrian athletes (23.6±1.8 yrs; ht = 161.8±5.0 cm; wt = 64.9±9.3 kg) to quantify aerobic power (VO$_2$max, VE$_{max}$, Time$_{max}$), anaerobic power (peak power, total work output, fatigue index), body composition (percent body fat, lean body mass), muscular strength (curl-ups, reverse sit-ups, pushups, handgrip strength), blood chemistries, and coronary risk profile. Results indicated that mean lean body mass and BMI fell within reported athletic norms for females. Handgrip strength (27.8±6.6 kg) was found to be lower than established norms for young females and the same was observed for mean VO$_2$max (33.9±4.5 ml/kg/min), treadmill time (10:06±:36 min:sec), and VE$_{max}$ (90.3±16.0 l/min) which were lower than predicted values while percent body fat (24.5±6.0 percent), however, was above average.

Singh et al. (1995) determined maximal oxygen consumption (VO$_2$max) and maximal workload attained (WL$_{max}$) in 28 Malaysian dragon boat rowers who were exercised to exhaustion on an arm ergometer. Right handgrip strength was found to be significantly (p < 0.001) greater than the left hand. Percentage body fat of the rowers was 11.8 (+/- 0.6) percent.

Tan et al. (2001) studied the grip strength measurement in competitive ten-pin bowlers. The conventional grip strength test was modified such that only the fingers used in holding the ball were tested. The study was concluded in two parts, each with a different study sample. Study 1 comprising of 39 members (26 males and 13 females), assessed the correlation between the bowling grip strength and bowling score whereas study 2 included 21 members (12 males and 9 females) to obtain the test-related reliability for both the bowling and conventional grip strength test, and to assess the agreement between two tests. The measurements were done for bowling grip strength, conventional grip strength, and bowling score. The test-retest reliability of the bowling
grip strength measurement ($r = 0.91$, $p < 0.01$) was comparable to that of the conventional five finger grip ($r = 0.93$, $p < 0.01$). According to the results the bowling grip strength test had high test-retest reliability, and a moderate agreement with the conventional grip strength test.

Koley and Yadav (2009) compared the handgrip strength (both right and left) and twelve anthropometric variables of cricketers with their control counterparts to search the correlation of handgrip strength with those anthropometric variables in cricketers. A total of 103 district and state level male cricketers from Amritsar, Punjab, India, aged 17–21 years (mean 18.29 ± 2.21) were selected purposively as the samples of the study along with an adequate control group ($n = 101$). Cricketers showed higher mean values in six variables and lesser mean values in seven variables than their control counterparts, showing statistically significant differences ($p \leq 0.05$) in all the variables (except arm muscle area) between them. In cricketers, right and left handgrip strength had significantly positive correlations with all the variables studied except percent lean body mass. It was concluded that handgrip strength might be an acceptable indicator for the excellent performance in cricket as well as a useful selection criterion for this sport.

Ivanovic et al. (2009) investigated functional dimorphism and model characteristics at maximal isometric handgrip force in top level athletes in the Republic of Serbia. 256 top level athletes were tested from taekwondo, waterpolo, track and fields, basketball, orienteering, volleyball, archery, boxing, judo, handball and power lifting teams. Significant difference was established for the measurement characteristics. Maximal average value $F_{\text{max HG iso}}$ for left and right hand was found in power lifters and minimal in taekwondo. The most expressed $F_{\text{max Nd/Do HG iso}}$ was found in handball. Considering defined classification of $F_{\text{max Nd/Do HG iso}}$, they classified the examinees from different sports in 4 groups: symmetry (volleyball, basketball, judo, boxing, power lifting 0.9337 to 0.9597); average (taekwondo, waterpolo 0.9076 to 0.9336); asymmetry (track and fields, orienteering, archery 0.8816 to 0.9075); dominant asymmetry of functional handgrip relations (handball <0.8815). The results obtained could be used to determine criteria decisions from the aspect of diagnostic procedures, metric aspect, and medical aspect.
Manning and Hill (2009) showed that running times over 50 m were positively correlated with 2D/4D in a sample of 241 boys (i.e. runners with low 2D/4D ran faster than runners with high 2D/4D). The relationship was also found for 50 m split times (at 20, 30, and 40 m) and was independent of age, body mass index, and an index of maturity. The associations between 2D/4D and sprinting speed were much weaker than those reported for endurance running. These results suggested that 2D/4D was a relatively weak predictor of strength and a stronger predictor of efficiency in aerobic exercise.

Gabbett (2009) did a study to investigate the physical qualities of junior rugby league players (under 14, 16, and 18) and to determine if pre-season fitness measures were significantly different for the players selected to play in the first competitive game of the season (i.e. starters) compared to the players not selected (i.e. non-starters). Eighty-eight junior (n=53 under 14; n =20 under 16; n=15 under 18) subelitie rugby league players underwent measurements of anthropometry, speed, change of direction speed (505 test), estimated lower body power (vertical jump), and estimated maximal aerobic power (multi-stage fitness test) at the beginning of the competitive season. Gabbett found that the relative importance of the different physical qualities differed between playing levels, starters tended to be taller, had faster change of direction speed, and greater playing experience than non-starters. Moderate to large effect size differences were detected between starters and non-starters for speed and estimated maximal aerobic power results.

Cortis et al. (2009) investigated the effect of chronic participation in soccer training on the improvement and the maintenance of inter-limb coordination performance across the lifespan and whether coordination was moderated by strength and power performances. They selected 40 young (12 +/- 1 years), 42 adult (26 +/-5 years), and 32 older (59 +/- 11 years) male soccer players and sedentary individuals who were administered in-phase and antiphase synchronized (80, 120, and 180 bpm) hand and foot flexions and extensions, handgrip and countermovement jump (CMJ) tests. Results showed that, soccer players always showed better performances than sedentary individuals regardless of age. It was found that chronic soccer training was beneficial to develop strength, CMJ, and inter-limb synchronization capabilities in children, to reach
higher levels of proficiency in adults, and to maintain performance in older individuals. The predicted role of CMJ on inter-limb coordination indicated that fine neuromuscular activation timing was central for both jump and coordinative performances.

Keane et al. (2010) compared performances in a motor test battery between elite female players and an age-matched reference group, to identify the fitness items that characterize top performers in the game. A total of 83 women aged 18-29 years completed a series of tests consisting of 8 items in the Eurofit Test Battery. Four of the test items contributed to group discrimination (endurance, flexibility, trunk strength, and limb speed). Based on percentage difference, the most prominent discriminator was the estimated VO$_{2\text{max}}$ (mean 49.9 ± 4.2 versus 39.7 ± 6.3 ml·kg$^{-1}$·min$^{-1}$). Grip strength and agility were also significantly superior in the Gaelic Football players (p < 0.05), who had significantly lower body fat values (23.3 ± 2.3 percent) than the reference group (27.2 ± 3.6 percent). The use of the Eurofit Test battery in games players was confirmed as were the multifactorial requirements of fitness for women playing this sport. It was concluded that elite Gaelic Football at top level is characterized mainly by high aerobic fitness, but a holistic training program is needed to cover the multiple fitness requirements of the game.

Reis et al. (2010) measured parameters related to the hydration status, glycemia, subjective perceived exertion and alteration in handgrip in 11 archers participating in two distinct competitions (indoor and outdoor), since the muscle contraction generated during the performance of the sports gesture increased the body temperature, glucose oxidation and the sweat loss. During the study, the athletes presented significant alterations in the parameters related to their hydration on different days, probably related to the adverse weather conditions in the outdoor events (34°C and 60 percent). The same situation was not observed for glycemia. The study proved straight relation between weather conditions and performance in high-level archers during competitive events, as well as evidenced non-invasive methods which would be recommended to assess the impact of these alterations.

Koley and Gupta (2012) evaluated the static balance and its correlation with selected anthropometric characteristics in 47 Indian elite male shooters aged 20-25 years. A total of ten anthropometric characteristics were measured i.e. height, weight, BMI,
biceps and triceps skinfolds, upper arm circumference in contraction and relaxation, percent body fat, percent lean body mass and dominant right handgrip strength. Standing balance test and stork balance test were also measured. An adequate number of controls were also taken. One way ANOVA indicated significant differences (p≤0.020-0.001) between shooters and their control counterparts in triceps skinfold, dominant right handgrip strength and standing balance test. Bonferroni post-hoc test indicated significant differences (p≤0.001) between pistol shooters and their control counterparts in triceps skinfold, between rifle shooters and controls (p≤0.006) in handgrip strength and between pistol shooters and controls (p≤0.020) in standing balance test. Dominant right handgrip strength was found to have significantly positive correlations with height, weight and upper arm circumference in contraction.

Ferragut et al. (2011) carried out a study to identify significant relationships between anthropometric variables and overhead throwing velocity in highly skilled male water polo players. Thirteen male water polo players, with a mean age of 26.10±4.82 years, were recruited from the Spanish Water Polo team and their anthropometric assessment was done. Throwing velocity was evaluated in three different situations from the 5 m-penalty line on the center of the water polo goal: A) throwing without a defender or a goalkeeper; B) throwing with a goalkeeper only, and C) armfuls running shot with goalkeeper. Maximal handgrip was also tested. They found that biacromial breadth had a significant correlation with handgrip in water polo players (r=0.792; p=0.001) and it also correlated with throwing velocity (r=0.716; p<0.001). Biepicondylar femur breadth correlated significantly with handgrip (r=0.727; p<0.05) and also with throwing velocity in throwing with goalkeeper situation (r=0.664; p<0.05). Handgrip showed a significant correlation with throwing velocity in throwing with goalkeeper situation (r=0.603; p<0.05).

Silva et al. (2011) evaluated changes in total-body water (TBW) and its compartments (extracellular water [ECW] and intracellular water [ICW]) and their relationship with loss of forearm maximal strength (FMS) in 27 elite male judo athletes. (age: 23.2 ± 2.8 years). They were again evaluated 1-3 days before competition. Handgrip was used to assess FMS. Using dilution techniques (deuterium and bromide), TBW and ECW were estimated, and ICW was calculated (ICW = TBW-ECW). Fat, fat-
free mass and appendicular lean soft tissue (LST) was assessed by dual-energy x-ray absorptiometry. Using a reduction of 2 percent as a representative outcome for decreased FMS, 10 athletes were identified as having lost FMS, whereas 17 changed <2 percent or gained. Results from baseline to before competition indicated that those who lost ≥2 percent of FMS significantly decreased TBW and ICW by $-2.7 \pm 3.0$ and $-4.4 \pm 4.2$ percent, respectively. The groups differed in ICW changes ($-4.4 \pm 4.2$ vs. $1.9 \pm 6.1$ percent), respectively, for those who lost FMS by ≥2 percent. The ICW changes, but not in TBW or ECW, significantly predicted the risk of losing FMS ($\beta = 0.206; p = 0.027$), even adjusting for weight and arm LST changes. The findings indicated that reductions in ICW increased the risk of losing grip strength in elite judo athletes.

Anderson (2011) investigated the physiological benefits of a university karate class in ten healthy women (age 20.8 +/- 0.6 years, body weight 58.9 +/- 2.4 kg, and height 163.8 +/- 2.2 cm) with no previous martial arts experience. Class sessions met twice per week for 50 minutes each session. Testing was done the first week of the class and during the last week of the 8 week course. Body composition, flexibility (modified sit-and-reach test), handgrip strength, and aerobic capacity (graded exercise treadmill test) were assessed. No significant differences due to the training were found for weight or body composition, while slightly higher values for handgrip strength were observed post training. Significant increase was observed in mean flexibility (25.5 +/- 3.3 cm versus 28.4 +/- 3.2 cm) and aerobic capacity (34.4 +/- 1.8 ml/kg/min versus 36.5 +/- 1.7 ml/kg/min) after karate training. It was concluded that eight weeks might not be adequate time to demonstrate the impact of karate training on certain markers of fitness. Handgrip strength was improved in the group, however not enough to demonstrate statistical significance.

Monsma and Malina (2005) investigated the variation in anthropometric characteristics and somatotype of female figure skaters. A total of 161 competitive female figure skaters aged 11-22 years (15.7±2.4 years) participated in the study and 15 anthropometric dimensions were measured on each skater. Results showed that test stream skaters had larger limb circumferences, estimated calf and arm musculature, and a thicker sum of skinfolds, and were more endomorphic than pre-elite skaters. Elite skaters were more mesomorphic than pre-elite skaters. The sitting height/stature ratio was
significantly lower in pre-elite skaters, while elite and test stream skaters did not differ in that indicator of proportions. Free skaters were taller and heavier; had a higher body mass index, limb circumferences and sum of skinfolds; and proportionally shorter legs than dancers and pair skaters. Free skaters, dancers and pair skaters, however, did not differ in somatotype. The results suggested that figure skating favored lightness, leanness, higher mesomorphy and lower endomorphy at more elite levels.