SUMMARY AND CONCLUSIONS

Introduction

The human hand is capable of complex and precise functions which can be divided into grasping abilities measured by the strength and manual dexterity. As a child grows up, the hand function develops (Haward and Griffin, 2002) with contribution of the increased hand anthropometry. Handgrip strength can be quantified by measuring the amount of static force that the hand can squeeze around an instrument called as handgrip dynamometer. While gripping, the muscles of the flexor mechanism in the hand and forearm create grip strength while the extensors of the forearm stabilize the wrist (Waldo, 1996).

Handgrip strength is widely used in adults as an indication of muscle strength in fitness testing (Bookwalter, 1950; Cotton and Johnson, 1968) and is seen as the single item most reasonably representative of total body strength (Tinkle and Montoye, 1961). Grip strength has been used as an indicator of overall muscle strength (Bassey and Harries, 1993; Koley et al., 2008). Handgrip strength is influenced by a number of factors including age, gender, handedness, motivation (Lennmarken et al., 1985) and position of extremity during test (Thorngren and Werner, 1979; Kuzala and Vargo, 1992). Also, a number of studies have demonstrated significant relationships between anthropometry and grip strength. As literature related to normative values of handgrip strength in Indian populations, especially from north India, is lacking, so the present study was planned.

Aims and Objectives

The aims of the present study were:

- To estimate the trends of handgrip strength in children, adolescents and adults of Amritsar covering a wide age range from 6-25 years.
- To study the gender differences on the basis of handgrip strength in various age groups.
- To search any association of handgrip strength with selected anthropometric traits of the population studied.
Summary and Conclusions

To estimate the handgrip strength of volleyball and softball players aged 18-25 years for performance enhancement and talent identification.

**Hypothesis**

Normative values of handgrip strength of Indian population would differ between two sexes and also from other populations. There would be some associations between handgrip strength and selected anthropometric traits in the studied population. There would be considerable differences in handgrip strength in sports persons of various sports events.

**Materials and Methods**

**Sample Selection**

A total of 2167 normal healthy individuals from both sexes, aged 6-25 years were selected purposively from Amritsar, Punjab. To estimate the handgrip strength of pre-adolescents of 6-10 years (n = 545) and adolescents (n = 566) of age group 11-15 years, samples were selected from different schools of Amritsar. Post-adolescents (n = 548) of age group 16-20 years were also selected from different schools and colleges of Amritsar. Young adults (n=508) aged 21-25 years were selected from different colleges and Guru Nanak Dev University, Amritsar, Punjab. A total of 114 volleyball players and 113 softball players aged 18-25 years were also considered as samples. These samples were taken from state and inter-university level competitions organized in Amritsar, Punjab, India. An equal number of controls were also taken. Study was conducted at various schools, colleges and Guru Nanak Dev University, Amritsar, Punjab, India from 2009-2012. Age of the subjects was estimated from their respective schools, colleges and university registers. The study was approved by the Institutional ethical committee. The subjects were informed about the purpose of the trial and had to give their signed informed consent before being enrolled.

**Methods**

**Estimation of handgrip strength**

The handgrip strength was measured using a standard adjustable digital handgrip dynamometer (Takei Scientific Instruments Co., LTD, Japan) at standing position with shoulder adducted and neutrally rotated and elbow in full extension. The dynamometer was held freely without support, not touching the subject’s trunk. The subjects were
asked to exert maximum force on the dynamometer thrice from their dominant and non-dominant hand. The maximum value in kilograms was recorded. Anthropometric equipment and handgrip dynamometer were calibrated before each assessment. All subjects were tested after 3 minutes of independent warm-up. Thirty seconds time interval was maintained between each handgrip strength testing.

**Anthropometric measurements**

Apart from the estimation of dominant and non-dominant handgrip strength, as many as 26 anthropometric characteristics namely, height, weight, body mass index, hand length, hand breadth, second digit length, fourth digit length, 2D/4D ratio, upper arm circumference, hip circumference, biceps skinfold, triceps skinfold, subscapular skinfold, suprailiac skinfold, calf skinfold, humerus biepicondylar diameter, femur biepicondylar diameter, upper arm length, forearm length, total arm length, arm muscle area, arm area, arm fat area, arm fat index, percent body fat and percent lean body mass were measured. All the anthropometric measurements were taken on each subject by following standard technique given by Lohman *et al.* (1988).

**Results and Discussion**

**Trends of handgrip strength and selected anthropometric characteristics**

In the present study, male and female students showed an increase in handgrip strength with age. The increase in dominant and non-dominant handgrip strength with age was approximately parallel for boys and girls until 13 years of age, after which male students were significantly stronger than female students similar to the earlier reports (Bohannon *et al.*, 2006; Bassey and Harries, 1993). Statistically significant differences (p<0.05-0.001) for dominant handgrip strength were found in 8, 9 and 14-25 years. For non-dominant handgrip strength also, statistically significant differences (p<0.05-0.001) were found in 9, 10 and 14-25 years. The stronger grip and taller figure of boys might be the effect of growth hormone after entering puberty (Sinclair and Dangerfield, 1998; Tanner, 1989).

Female students too displayed similar trends of gradual increments both in dominant and non-dominant handgrip strength, but they showed lower mean values than their male counterparts. The sex differences in handgrip strength are likely due to higher
levels of androgenic hormones (Page et al., 2005), greater muscle mass (Kallman et al., 1990) and greater height and weight in males (Kamarul et al., 2006; Kuh et al., 2006).

In male and female students, there was an increase in the mean value of almost all the anthropometric characteristics with the progression of age. Male students showed higher mean values for height than female students in all age groups except 6, 7 and 10-13 years. A consistent increase in height was observed in male students for all the age groups except 20-22 and 24 years. Similar trends were observed for female students too showing continuous increments of height upto the age of 18 years.

For weight, the mean values continued to rise up to 21 years in male students and up to 18 years in female students. However, female students showed a slight increase in the mean values than male students in the pre-pubertal age group of 10-13 years. Amongst male students, the mean values for BMI showed an irregular trend from 6-12 years, followed by a steady increase up to 18 years. In case of female students, the mean values for BMI showed a steady trend of increment from 6-25 years of age group (except in 16, 19, 21 and 23 years).

In male students, mean values of hand length increased sharply as compared to female students from 14 to 25 years whereas in female students, it increased up to 15 years. For hand breadth, male students recorded higher mean values than their female counterparts in all age groups (with some exceptions). For 2nd digit length, increasing trends were observed in male students up to 17 years. In female students, a continuous increase in the mean values of this trait was seen from 6 to 18 years. The mean values for 4th digit length continued to rise up to 17 years in male students and up to 13 years in female students. In case of 2D/4D ratio, an irregular trend was observed in both the sexes.

Male and female students showed almost similar gradual increasing trends for upper arm circumference up to 15 years with male students exhibiting higher mean values than female students from 16 years onwards. Upper arm circumference is reported to change with onset of puberty (Gasser et al., 1993) and also rises progressively throughout adolescence at a rate greater than that in early childhood (Frisancho, 1981). Hip circumference among male students continued to increase from 6-20 years and from 6 to 25 years in female students (with the exception in 19 and 22 years). However, female students showed higher mean values for hip circumference as compared to male students.
in 7, 8, 10-16 and 24-25 years. The greater relative hip circumference in female students than male students is largely due to the specific stimulation of cartilage cells by oestrogens in females (Harrison et al., 1988).

An irregular pattern of variation of skinfolds with age was observed both in male and female students. Female students showed almost higher mean values of skinfolds than male students in almost all the age groups which was similar to the earlier studies (Raizada et al., 1990; Oyewale et al., 2010) indicating more fat deposition in puberty. In the present study, the mean calf skinfold thickness was the highest and biceps skinfold thickness was lowest in both the sexes from 6 to 25 years. Female students showed a sharp rise in the mean values between the age group of 10-15 years for the biceps skinfold, 14-17 years for the triceps skinfold, 11-15 years for the subscapular skinfold, 11-17 years for the suprailiac and calf skinfolds. Male students of age 15 years recorded a sharp decline in the mean values for all skinfold parameters which may be attributed to greater lean body mass in males at puberty with the influence of testosterone and fatty deposits in females with oestrogen and progesterone. With the onset of puberty, the rate of subcutaneous fat deposition and fat distribution are changed, as measured by skinfold thickness (Martinez et al., 1993; Gasser et al., 1993).

In male students, a continuous increase in mean values of upper arm length, forearm length and total arm length was observed up to the age of 19 years. In female students, the increment of this trait was observed up to 15 years for upper arm length, 13 years for forearm length and 18 years for total arm length. However, male students showed a steady increase in the mean values between 16-19 years for these variables. Male students recorded higher mean values for forearm length than females from 14 years onwards and it is probably due to laying down in early foetal life of slightly more active tissue in this area in males (Harrison et al., 1988). Male students showed higher mean values in humerus and femur biepicondylar diameters and arm muscle area than female students in all the age groups as reported in earlier studies (Toselli et al., 2006).

Male students showed increasing trends for arm area in almost all ages except in 7, 10, 14, 21, 24 and 25 years. Female students showed increasing higher mean values of arm area till 15 years after which it showed an irregular pattern with a maximum mean value in the age of 25 years. Increasing trends were also observed for arm fat area in male
and female students from 6-12 years followed by some irregular trends. Irregular trends for arm fat index in female students were also observed. This may be due to increase in fat deposition as a secondary sexual characteristic. Higher mean values were observed for percent body fat and lower values for percent lean body mass in female students as compared to their male counterparts in all age groups.

**Correlations of Handgrip Strength with Selected Anthropometric Characteristics**

**Bivariate Correlation**

In the context of simple Karl Pearson’s product moment correlations, significant correlations (p<0.05-0.01) of dominant and non-dominant handgrip strength was found with almost all the anthropometric characteristics studied. Both dominant and non-dominant handgrip strength showed statistically significant (p<0.05-0.01) positive correlations with height, body weight, BMI, hand length, hand breadth, 2nd digit length, 4th digit length, upper arm circumference, hip circumference, humerus and femur biepicondylar diameters, upper arm length, forearm length, total arm length, arm muscle area and arm area in the age groups of 6-10 years, 11-15 years, 16-20 years, 21-25 years, with arm fat area (in all age groups except 16-20 and 21-25 years in dominant handgrip strength and only in 6-10, 6-25 years with non-dominant handgrip strength), percent lean body mass (only in 16-20 and 21-25 years), biceps skinfold (in all age groups except 16-20 years), triceps, subscapular, suprailliac and calf skinfolds (only in 6-10, 11-15 and 6-25 years). Significantly negative correlations (p<0.05-0.01) of dominant and non-dominant handgrip strength were found with triceps and calf skinfolds, percent body fat (in 16-20 and 21-25 years), arm fat index (in all age groups except 6-10 years). Non-dominant handgrip strength showed significant negative correlations (p<0.05-0.01) with subscapular skinfold in the age group of 16-20 years and 2D/4D ratio in 21-25 years.

**Linear regression**

Linear regression showed highly significant (p<0.05-0.001) correlations of both dominant and non-dominant handgrip strength with all the anthropometric characteristics studied in all age groups except 2D/4D ratio (except 21-25 years in NDHG), biceps skinfold (in 16-20 years), subscapular (16-20 years in DHG and 21-25 years in DHG and NDHG), suprailliac (16-20 and 21-25 years) skinfolds, arm fat area (in 16-20 and 21-25 years).
years), arm fat index (in 6-10 years), percent body fat and percent lean body mass (only in 6-10 and 11-15 years).

**Multiple regression**

Multiple regression of dominant handgrip strength with anthropometric characteristics in male and female students of 6-10 years showed that hand length ($t = 1.93$), hand breadth ($t = 2.389$), non-dominant handgrip strength ($t = 16.466$) and arm muscle area ($t = 1.985$) correlated significantly ($p<0.05-0.001$) ($R^2 = 0.813$). In the age group of 11-15 years also, only hand breadth ($t= 2.873$), non-dominant handgrip strength ($t = 20.555$) and triceps skinfold ($t = 1.976$) showed significant correlation ($p<0.05-0.001$) with dominant handgrip strength ($R^2 = 0.872$). In the age group of 16-20 years, significant correlations ($p<0.05-0.001$) were observed with hand length ($t = 2.088$), hand breadth ($t = 4.322$), hip circumference ($t = 2.066$), suprailiac skinfold ($t = 2.664$), upper arm length ($t = 1.975$), forearm length ($t = 2.004$) and total arm length ($t = 2.002$) and percent body fat ($t = 4.410$) ($R^2 = 0.758$). In the age group of 21-25 years, significant correlations ($p<0.05-0.001$) of dominant handgrip strength were observed with non-dominant handgrip strength ($t = 11.858$), suprailiac skinfold ($t = 2.274$) and calf skinfold ($t=3.054$) ($R^2 = 0.901$). Multiple regression of non-dominant handgrip strength with anthropometric variables in male and female students of 6-10 years showed that only dominant handgrip strength ($t=16.570$) correlated significantly ($p<0.05-0.001$) ($R^2 = 0.781$). In the age group of 11-15 years also, only dominant handgrip strength ($t=20.555$) and arm fat area ($t= 2.038$) showed significant correlation ($p<0.05-0.001$) with non-dominant handgrip strength ($R^2 = 0.865$). In the age group of 16-20 years, significant correlations ($p<0.05-0.001$) were observed only with dominant handgrip strength ($t=24.816$) ($R^2 = 0.917$). In the age group of 21-25 years, significant correlations ($p<0.05-0.001$) were observed only with upper arm circumference ($t=11.858$) and percent body fat ($t=2.045$) ($R^2 = 0.889$).

**Evaluation of Handgrip Strength in Sports Persons**

The present study evaluated the handgrip strength and selected anthropometric characteristics in male and female volleyball and softball players. The findings were compared with their control counterparts and recorded certain trends.
Volleyball

In the present study, male volleyball players showed higher mean values than female players for all the variables except BMI, 2D/4D ratio, hip circumference, biceps skinfold, triceps skinfold, subscapular skinfold, suprailic skinfold, calf skinfold, upper arm length, arm fat area, arm fat index and percent body fat. Highly significant differences (p<0.05-0.001) were noted among them for all the variables except BMI, 2D/4D ratio, subscapular skinfold and arm fat area. The high posture constitutes a critical factor for the volleyball players so that they could manage to meet the ball at the maximum height above the net.

When compared with controls, the male volleyball players showed higher mean values for all the variables except BMI, upper arm circumference, hip circumference, all skinfolds, arm fat area, arm fat index and percent body fat. Highly significant differences (p<0.001) were observed in height, BMI, hand length, 2nd digit length, 4th digit length, non-dominant handgrip strength, biceps, triceps, subscapular, suprailic and calf skinfolds, forearm length, total arm length, arm fat area, arm fat index, percent body fat and percent lean body mass between them. Higher values of height in male players as compared to control group may be attributed to the fact that volleyball elite athlete prerequisite to have greater height and strength in wrist and fingers, due to the nature and the type of the sport. In the present study, the estimated percent body fat of the volleyball players was less and percent lean body mass of both the sexes was higher than controls in both sexes, similar to the findings of Koley and Singh (2012).

Female volleyball players showed higher values for all variables except hand breadth, upper arm circumference, biceps, triceps, subscapular, suprailic and calf skinfolds, femur biepicondylar diameter, arm muscle area, arm area, arm fat area and percent body fat as compared to control counterparts. Highly significant differences (p<0.05-0.001) were observed for height, weight, hand length, 2nd digit length, 4th digit length, dominant and non-dominant handgrip strengths, biceps skinfold, humerus and femur biepicondylar diameters, upper arm length, forearm length and total arm length between female volleyball players and controls. Female players showed higher mean values for height, weight, and percent body fat, and lower mean values for percent lean body mass as compared to the findings reported earlier by Koley and Singh (2012).
Summary and Conclusions

An excessive amount of adipose tissue is considered as an unused mass, because the athlete’s body has to repeatedly cope with gravitation during locomotion and jumps (Reilly, 1996) which results in a lowering of performance and an increase of demands on energy during the performance of a particular action. In the present study, female volleyball players showed higher mean values of body fat (26.53 percent) as compared to the findings of Malousaris et al. (2008). The results obtained for female volleyball players in our study showed BMI value of 21.45 kg/m² which was less than the Cuban female volleyball players (22.8 kg/m²) as reported by Carvajal et al. (2012).

Softball

Softball is a direct descendant of baseball. It requires speed, strength and endurance (Trebizan et al., 1996). Softball players require a significant amount of upper body muscle balance due to the specificity of the underarm activity.

In the present study, male softball players recorded higher mean values than their female counterparts for all the variables except for biceps, triceps, suprailiac and calf skinfolds, arm fat area, arm fat index and percent body fat. Male softball players showed higher handgrip strength than female players. Statistically significant differences (p<0.05-0.001) were observed for softball players for all the variables except 2D/4D ratio, biceps and subscapular skinfolds, and arm fat area. Male and female softball players showed lower mean values for hand length and comparable value of hand breadth, 2D/4D ratio as compared to the earlier reports of Koley and Kumaaar (2011, 2012).

Both male and female softball players showed higher mean values for dominant and non-dominant handgrip strength than their control counterparts. This trend was similar to the earlier reports (Koley and Kumaaar, 2012). This could be due to regular physical exercise and practice of male and female players. Male players showed lower mean values for all the skinfold measurements except subscapular skinfold. It may be due to sexual dimorphism and training effects. Female softball players showed lower mean values for dominant and non-dominant handgrip strength as compared to the findings by Giardina et al. (1997) but showed significant differences (p<0.05-0.001) in the dominant and non-dominant handgrip strength, similar to the reports of Koley and Kumaaar (2011). Female softball players had lower mean values in height, weight and BMI, and higher
value in percent body fat as compared to the earlier reports for the female handball players (Leyk et al., 2007).

In the present study, male softball players showed higher mean values for height, hand length, 2nd digit length, 4th digit length, dominant handgrip strength, non-dominant handgrip strength, humerus biepicondylar diameter, femur biepicondylar diameter, forearm length, arm fat index and percent body fat than their control counterparts. Statistically significant differences (p<0.05-0.001) were found for non-dominant handgrip strength, upper arm circumference, femur biepicondylar diameter, upper arm length, arm muscle area, arm area, percent body fat and percent lean body mass. It may be due to genetic predisposition and growth affected by sports activity.

When female softball players were compared with their control counterparts, it was found that they had higher mean values for height, dominant and non-dominant handgrip strength, hip circumference, humerus and femur biepicondylar diameters, upper arm length, forearm length, total arm length and percent lean body mass than their control counterparts. However, statistically significant differences (p<0.05-0.001) were found between female softball players and controls in dominant handgrip strength, non-dominant handgrip strength, upper arm circumference, biceps skinfold, femur biepicondylar diameter, arm muscle area and arm area.

Conclusions
The findings of the preset study were concluded as follows:
1. In the present study, male and female students showed an increase in handgrip with age. The increase in dominant and non-dominant handgrip strength with age was approximately parallel for male and female students upto 13 years of age, after which male students were significantly stronger than female students.
2. Statistically significant differences (p<0.05-0.001) for dominant handgrip strength were found in 8, 9, and 14-25 years between male and female students.
3. Statistically significant differences (p<0.05-0.001) for non-dominant handgrip strength were found in 9, 10 and 14-25 years between male and female students.
4. Anthropometric characteristics such as height, hand length, hand breadth, 2nd and 4th digit length, humerus biepicondylar diameter, forearm length, total arm length,
arm fat index showed significant differences (p<0.05-0.001) from 14-25 years between male and female students.

5. Percent body fat and percent lean body mass showed significant differences (p<0.05-0.001) from 6-25 years between male and female students.

6. Both dominant and non-dominant handgrip strength were found to have statistically significant positive correlations with height, weight, BMI, hand length, hand breadth, 2nd digit length, 4th digit length, upper arm circumference, hip circumference, humerus and femur biepicondylar diameters, upper arm, forearm and total arm length, arm muscle area, arm area, arm fat area and all skinfolds from 6-25 years.

7. Both dominant and non-dominant handgrip strengths were found to have significant negative correlations with arm fat index in the age group of 6-25 years.

8. Statistically significant differences (p<0.05-0.001) were found for body weight from 16-25 years between male and female students.

9. Statistically significant differences (p<0.05-0.001) were found for BMI in 6, 17-23 years between male and female students.

10. Statistically significant differences (p<0.05-0.001) were found for biceps skinfold in 8, 10, 11, 15, 16 years, for triceps skinfold in 7, 8, 10-12, 15-17, 19, 20, 22, 23 and 25 years, for subscapular skinfold in 8, 11-16, 19 and 25 years, for suprailiac skinfold in 7, 8, 10-16, 20 and 25 years and for calf skinfold in 7, 11-13, 15, 16, 19-25 years between male and female students.

11. Statistically significant differences (p<0.05-0.001) were found in femur biepicondylar diameter in male and female students in 7-10, 13-20 and 22-23 years.

12. Statistically significant differences (p<0.05-0.001) were obtained in upper arm length in the age of 11, 16-23 years between male and female students.

13. Statistically significant differences (p<0.05-0.001) were obtained in arm muscle area in the age of 8, 9, 14-24 years between male and female students.

14. Statistically significant differences (p<0.05-0.001) were found in arm area in the age of 14, 17-24 years, upper arm circumference in the age of 17-23 years and hip circumference in 11-13, 15, 19-22 years between male and female students.
15. Statistically significant differences (p<0.05-0.001) were found in arm fat area in 7, 8, 10, 12, 14-16 and 25 years between male and female students.

16. Statistically significant differences (p<0.05-0.001) were found in all the parameters except BMI, 2D/4D ratio, subscapular skinfold and arm fat area between male and female volleyball players.

17. Statistically significant differences (p<0.05-0.001) were found in all the parameters except 2D/4D ratio, biceps and subscapular skinfolds and arm fat area between male and female softball players.