Chapter 2
Review of Literature
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, PMC, CINHAL, Sciencedirect.com as well as from the libraries of Guru Nanak Dev University, Amritsar, VMMC Delhi and National Medical Library, New Delhi.

2.1. Dynamometric Strength Measurements

Baltzopoulos et al. (1989) studied Isokinetic dynamometry; its applications and limitations. The most frequently used isokinetic parameters are the maximum torque and the angular position where it was recorded, the torque output at different angular velocities of movement, the torque ratio of reciprocal muscle groups and the torque output during repeated contractions. The unique features of isokinetic dynamometry are optimal loading of the muscles in dynamic conditions and constant pre-selected velocity of movement. Isokinetic dynamometry has also been used for the training of various muscle groups in order to improve the muscular performance in dynamic conditions. The movement velocity of different activities can be simulated during training in order to improve the training effect. Data acquisition and analysis have been improved by using computer systems interfaced to isokinetic dynamometers.

Walmsley et al. (1993) reviewed an overview of isokinetic dynamometry and concluded that isokinetic dynamometry offers distinct advantages, both clinically and for research, in the evaluation and treatment of muscle performance.

Charteris (1999) studied effects of velocity (30 and 180 degree/sec) on upper to lower extremity muscular work and power output ratios of inter-collegiate athletes. The study evaluated isokinetic performance variables, particularly (a) flexor to extensor work and power output ratios of upper and lower extremities and (b) overall upper to lower extremity work and power ratios, in inter-collegiate athletes. Results suggested that that at the speeds tested all torque responses exhibited velocity related decrements at rates that kept flexor to extensor ratios and upper to lower extremity ratios constant (p
> 0.05) for work and power. All upper extremity relative torque, work, and power flexion responses were equal to extension responses (p > 0.05) regardless of speed. Conversely, all lower extremity relative measures of torque, work, and power of flexors were significantly lower than extensor responses. In the case of both upper and lower extremities, work and power ratios were unaffected by speed. Moreover, increasing speed from 30 to 180 degrees/s had no effect on upper to lower extremity work and power ratios, whether for flexion, extension, or flexion and extension combined. Knowledge of normal upper to lower extremity work and power output ratios at slow to moderately fast isokinetic speeds is particularly useful in cases of bilateral upper (or lower) extremity rehabilitation, when the performance of a contralateral limb cannot be used as a yardstick.

2.1.1. Trunk Strength

Madsen (1976) assessed short-term and long-term reproducibility of several strength variables in trunk extensor and flexor muscle by Cybex 6000 dynamometer (Lumex, Inc., Ronkonkoma, NY). Isokinetic trunk extensor and flexor strength (peak torque, total work, power acceleration time, and torque acceleration energy) at 30 degrees/sec, 120 degrees/sec, and 180 degrees/sec and isometric extensor and flexor peak torque were measured in 24 healthy women. Result of the study revealed substantial between-subject variation of coefficients of variation for all strength variables; for example, the 80% central range for individual coefficients of variation for long-term reproducibility of extensor strength measurements at 30 degrees/sec ranged from 2.5% to 19.5%. Critical differences calculated using the pooled variances for long-term reproducibility were higher than 20% for all measures, mounting to 80% for acceleration time. Strength testing is of limited value in the individual subject because of considerable day-to-day variability.

Viitasalo et al. (1985) studied the maximal isometric muscular strength and anthropometric characteristics among three random samples (31–35, 51–55 and 71–75 years) each containing 180 Finnish men with a mean age of 32·9 ± 1·4, 53·1 ± 1·5 and 72·7 ± 1·4 years. Strength was measured on dynamometers for grip, trunk and knee extension and trunk and elbow flexion. The anthropometric characteristics included
body height, weight, body mass index, skeletal weight, fat weight and a weight factor. The youngest cohort had the highest and the oldest cohort the lowest values for strength as well as body height and fat-free body weight, while the middle-aged group had the highest and the youngest group the lowest values for body weight, fat weight, body mass index and for the weight factor. In correlation analysis grip strength was found to have the highest correlation with chronological age and to be least affected by the anthropometric variables among the strength variables studied. On a percentage scale, the decline of strength from the youngest to the oldest cohort was in the order: knee extension (47%), handgrip (42%), trunk extension (42%), trunk flexion (35%) and elbow flexion (35%). The body mass index was found to be an important variable to be controlled in studying differences between age groups in muscle strength.

Andersson et al. (1988) studied trunk muscle strength in athletes. The maximal voluntary strength of the trunk and hip muscles was measured in 57 male elite athletes (soccer players, wrestlers, tennis players, and gymnasts), 14 female elite gymnasts, and in a normal group of 87 conscripts during flexion, extension and lateral flexion. The constant angular velocities used were 15 deg/sec. and 30 deg/sec, respectively. Isometric strength was measured in a straight body position (0 deg. of flexion). All male athlete groups showed higher peak torque values than the normal. The differences were largest in hip extension and trunk flexion. The male gymnasts also showed significantly higher peak values in hip flexion as compared to all other categories. There was no difference in strength per kg body weight between female gymnasts and untrained males, except in trunk extension. The position for peak torque occurred earlier in the movements for the athletes, especially for the gymnasts in extension movements and for the tennis players in flexion movements. In isometric contractions essentially the same strength differences were present as in the slow isokinetic contractions. In lateral flexion wrestlers and tennis players showed significantly higher strength in movements toward the non-dominant side. Thus, differences were present between the athletes and the normals, some of which appeared to be sport specific and related to long-term systematic training.

Sunnegårdh et al. (1988) conducted a study to determine isometric muscle strength of the handgrip and of trunk flexion and extension, and isokinetic torque of
elbow and knee flexion and knee extension in 8 and 13 year old Swedish children. The muscle strength variables were in general found to be very similar in the 8 year old boys and girls. In the 13 year old group, the boys were generally stronger than the girls. The torque values were higher in the older than in the younger children, with the exception of trunk strength per unit of body weight and of lean body mass, which were similar in boys of both ages and significantly lower in the older than in the younger girls. No significant correlation was found between the estimates of physical activity and isometric and isokinetic muscle strength and torque.

Perrin et al. (1991) examined bilateral and reciprocal concentric strength relationships of the thigh musculature in variety of athletic populations. Twenty-one habitual female runners were assessed for trunk and hip strength via isokinetic dynamometry (KinCom, Chattex Corp.). Eccentric strength at the trunk was greater than concentric strength, similar results were found at the hip. Reciprocal muscle group ratios revealed that concentric trunk flexion was 52% of extension. Eccentric trunk flexion was 39% of extension. Concentric hip flexion was 98% of extension. Eccentric hip flexion was 103% of extension, the ratios were not significantly different. These findings established previously unreported isokinetic strength values for the trunk and hip in female runners.

Kort et al. (1992) conducted a study to establish referential isokinetic strength parameters in competitive judo athletes Twenty-eight male top judo athletes and 34 top racing cyclists, were tested by means of the Cybex Trunk Extension Flexion unit and the Torso Rotation unit at four different speeds-30, 60, 90 and 120 degrees/sec. Result of the study suggested that the ratios of flexion to extension and left rotation to right rotation were not significantly different between the cyclists and the judo athletes. The findings concluded that for clinical purposes, the ratios of flexion to extension and left rotation to right rotation might be of more importance than separate values as such. The study also suggested that research in this area was of utmost importance to provide a needed shift in emphasis from injury treatment to injury prevention.

Greve et al. (1997) conducted a study to evaluate isokinetic trunk flexion and extension in normal sports persons (n=13) and sedentary people (n=17). The parameters
analyzed were peak torque, total work and average power, Group 1: peak torque 80% at 60 degrees, total work and average power is nearly 100%; Group 2: peak torque, total work and average power is closed to 100%, at 60 degrees. The flexor muscles values were reported to be higher than the extensor muscles, which meant the abdominal muscles were stronger than the spine erector muscles.

Karataş et al. (2002) conducted a study to determine the intra-rater and inter-rater reliability of reciprocal concentric trunk flexion and extension peak torque values at different angular velocities using the Cybex NORM isokinetic dynamometer. Trunk flexor and extensor muscles of 15 healthy subjects were assessed at 60 degrees/sec and 90 degrees/sec angular velocities by two physicians three times, with at least 48 hour rest between test sessions. For intra-rater reliability intra-class correlation coefficients for trunk flexion, peak torque values ranged from 0.89 to 0.95; for the extensors, values ranged from 0.80 to 0.92. The intra-class correlation coefficient values for inter-rater reliability were also found to be highly reliable, and peak torque values demonstrated intra-class correlation coefficients values that ranged from 0.95 to 0.98. Reciprocal concentric trunk flexion and extension peak torque measurements at 60 degrees/sec and 90 degrees/sec angular velocities had a high intra-rater and inter-rater reliability with the Cybex NORM isokinetic dynamometer in healthy subjects.

Sinaki et al. (2001) studied the effect of gender, age, and anthropometry on axial (back extensor strength and appendicular muscle strength (upper limbs-grip, and lower limbs-knee extensors). Anthropometric measurements and body mass index were also assessed. Group comparisons were made for each decade. Back extensor strength in subjects aged 20 to 89 year ranged from 93 to 832 N in men and from 71 to 440 N in women. i.e. muscle strength in women was less than that in men at all ages. There was a 64% loss of back extensor strength in men from the peak in their fourth decade (556 N) to the lowest level in their ninth decade (201 N). Women experienced a 50.4% loss from the peak in their fifth decade (306 N) to the lowest level in their ninth decade (152 N). It was concluded that men had a greater loss of back extensor strength than women with increasing age. In both genders, there was more loss of back extensor strength than appendicular muscle strength. Reduction in back extensor strength in women coincided
with increased body mass index in older age. In women, there was a negative correlation between body weight and level of physical activity, whereas this finding was not evident in men. This cross-sectional study showed that physiologic reduction of muscle strength, which began early in life, later stopped and that muscle strength even improved, despite the aging process. Therefore, strengthening exercises at any age was encouraged to prevent the impact of several age-related musculoskeletal challenges.

Danneskiold et al. (2009) studied Isokinetic and isometric muscle strength in a healthy population with special reference to age (20-80 years) and gender. Randomly selected subjects then sub-grouped according to age and gender. Isometric and isokinetic muscle strength was measured in each subject across the main joints in the body in the three main muscle groups viz. upper limbs, trunk and lower limbs. Muscle strength in healthy men decreased in a linear fashion from the age of 25 years down to between 54% and 89% at the age of 75 years, and seems not highly dependent on any other parameter than age. For women, the muscle strength is dependent on weight and is only related to age from around 40 years of age. The decrease in muscle strength from the age around 40 to 75 years was 48-92%. For most muscle groups, men were 1.5-2 times stronger than women, with the oldest men having strength similar to that observed among the youngest women. In all age groups, women have lower muscle strength than men. Men's muscle strength declined with age, while women's muscle strength declines from the age of 41 years.

Clayton et al. (2011) determined the relationships between isokinetic core strength and multiple measures of athletic performance in male collegiate baseball athletes. Subjects included 29 male collegiate baseball players (20.4 ± 1.6 years). All subjects participated in 5 data collection sessions, including two familiarization meetings. Data collection included measures of body composition, athletic performance tests, and isokinetic core strength. The primary finding of this research was that the Backwards Overhead Medicine Ball throw consistently produced significant correlations with all measures of isokinetic core strength, with the highest correlation observed between the Backwards Overhead Medicine Ball throw and trunk flexion (r = 0.680; P≤0.05). Statistically significant relationships were also found between trunk
flexion and body weight, body mass index, percent body fat, fat weight, and body weight. The complexity of core musculature must be considered when selecting assessments of core strength, with special attention to their impact on sport specific movements.

Van-Damme et al. (2013) investigated relative muscle activity and ratios of local to global muscle activity at the different velocities of isokinetic movements on a Cybex dynamometer. Fifty-three healthy employees of Belgian Defence (26 males and 27 females) aged between 20 and 57 years old voluntarily performed isometric and isokinetic exercises at four different velocities. Surface electromyographic signals of different abdominal and back muscles were recorded on both sides. Both the relative muscle activity and the local to global muscle activity ratio of the back muscles were affected by changes in velocities of isokinetic exercises. The global muscle system was more influenced by changes in velocity, than the local muscle system. Abdominal relative muscle activity and ratios were not influenced by velocity of movement. This study revealed that the velocity of isokinetic extension exercises influences the recruitment of the back muscles, meaning that protocols of training programs should be adapted in function of the focus of the therapy.

2.1.2. Shoulder Strength

Reid et al. (1989) carried out a study on shoulder muscle strength using an isokinetic dynamometer device, and normal parameters were established on 20 male and 20 female athletes for a total of 80 shoulders with a mean age of 26·65 years and 25·35 years for the female and male athletes respectively. Peak torque, angle of peak torque, and arc of maximum strength were measured in that study. For all movements women were approximately 50% as strong as men. There were no significant differences between the means for dominant versus non-dominant arms. The strongest muscle group was the adductors, with a mean peak torque of 28·8 Nm for female athletes and 48·0 Nm for male athletes. With 48 Nm internal and external rotation, women had a significantly greater range of motion than men but the peak torques remained around the neutral position.
Hortobagyi and Katch (1990) studied eccentric and concentric torque-velocity relationships during arm flexion and extension. Forty men were tested with a dynamometer for concentric and eccentric torques during arm flexion and extension at 30°/s, 90°/s and 120°/s. The subjects were placed into a high strength (HS) or low strength (LS) group. The eccentric and concentric segments of the torque-velocity curves (TVCs) were generated using peak torque and constant-angle torque (CAT) at 1.57 and 2.36 rad. Angle of peak torque was also recorded. Statistical analysis revealed that torque output in low strength plateaued at low concentric velocities and was also flattened with increasing eccentric velocities. Conversely, torque output for high strength increased with decreasing concentric velocities and increased with increasing eccentric velocities. The method of plotting the TVCs for peak or CAT did not influence the pattern of TVC. Eccentric flexion peak torque occurred at a significantly shorter muscle length (1.88 rad) than concentric torque (2.12 rad). This difference was also present for extension; it was 1.88 rad for eccentric and 2.03 rad for concentric torque.

Wang et al. (2000) evaluated the differences in strength and mobility of shoulder rotator muscles in the dominant and non-dominant shoulders of elite volleyball players. Isokinetic muscle strength tests were performed at speeds of 60 and 120°/s, and shoulder mobility was examined in ten players from the England national men’s volleyball squad. The subjects also completed a questionnaire that included a visual prompt and analogue pain scale. Results suggested that the range of motion of internal rotation on the dominant side was less than that of the non-dominant side (p<0.01). The average peak strength at 60°/s external eccentric contraction was lower than that of internal concentric contraction in the dominant arm, but was higher in the non-dominant arm. Six of the ten subjects reported a shoulder problem, described as a diffuse pain located laterally on the dominant shoulder. These elite volleyball players had a lower range of motion (internal rotation) and relative muscle imbalance in the dominant compared with the non-dominant shoulder.

Gozlan et al. (2005) compared lateral rotator and medial rotator muscle strength of both shoulders in a sport involving asymmetrical movements (tennis), symmetrical movements (swimming), and symmetrical and asymmetrical movements (volley-ball).
Retrospective study of 42 healthy elite athletes (14 tennis players, 19 swimmers and 9 volleyball players). The strength of lateral and medial rotators of both shoulders by Cybex Norm® isokinetic dynamometer, in the concentric mode, in the modified Davies position, at two different speeds (60°/s and 180°/s) was evaluated and peak torque of lateral and medial rotators and lateral and medial rotators ratios was analysed. Result showed that the medial rotator peak torque of the dominant shoulder was significantly higher than that of the non-dominant shoulder. The lateral and medial rotators ratio of the dominant shoulder was significantly lower than the non-dominant shoulder in women. In swimming; the lateral rotator strength and lateral and medial rotators ratio of the dominant shoulder was higher than the non-dominant side in men at 60°/s. Both shoulders showed comparable strength in women. In volleyball: shoulder muscular strength was symmetrical. The higher strength of medial rotator muscles in the dominant shoulder of tennis players (asymmetrical movements) has been reported in the literature. Athletes show asymmetrical shoulder strength in swimming, a symmetrical sport and similar lateral and medial rotators strength in both shoulders in volleyball, a sport with asymmetrical movements. To our knowledge, these results had never been reported before.

Lertwanich et al. (2006) determined the difference in isokinetic peak torque of dominant and non-dominant shoulders. 39 healthy subjects (24 men, 15 women) were tested isokinetically by dynamometer at two angular velocities (60°/s and 180°/s) during abduction, adduction, flexion, extension, internal rotation and external rotation. There were statistical differences of contralateral peak torque in almost all directions of shoulder muscle contractions, except in shoulder flexion at both speeds. Peak torque of shoulder adduction, extension, and internal rotation were greater in the dominant side. Shoulder abduction and external rotation peak torque were greater in the non-dominant side. Therefore, clinicians should not directly use the isokinetic strength of the contralateral shoulder as normal baseline data for an injured side without consideration.

Linde et al. (2011) conducted a study to detect significant differences in muscular performance strength values of the muscles of the rotator cuff by isokinetic tests in two overhead sport specialities: viz. waterpolo (n = 30) and tennis (n = 6).
Results of the study suggested that peak torque in dominant limb was stronger than non-dominant for both sports but differences in tennis players were much higher in favour of the dominant than waterpolo players with specific reference to internal rotators. With regard to MRW, waterpolo players had values higher than tennis players in external rotators of both sides but the internal rotators of the dominant limb were greater in tennis players. It has been concluded that due to the environment, the waterpolo players developed specific work and the symmetrical content of swimming, the ratios in both extremity were very symmetrical (related to peak torque); in tennis players the dominant limb had more normal ratio values but that didn’t happen in the non-dominant, possibly because it came into play shortly.

2.1.3. Elbow Strength

Otis et al. (1983) examined the relationship between maximal isokinetic and maximal isometric torque at angular velocities of 24, 48, 96, and 192°/s for both flexion and extension of the elbow joint. Twenty-four subjects were tested bilaterally, and discrete torque values at the positions of 60 and 90° of flexion were obtained from the continuous isokinetic records for comparison with isometric torques recorded at the same two positions. Data were analyzed using an analysis of covariance with isokinetic torque, the dependent variable, expressed as a function of isometric torque and as a function of the design variables side and position. The results demonstrated significant effects of side and position and also demonstrated the dependence of isokinetic strength on velocity. Confidence intervals were determined for the prediction of isokinetic torque from observed isometric torque for normal individuals, providing a potentially useful tool to aid in the diagnosis of muscular disorders.

Griffin (1987) studied the torque-velocity relationships during concentric, eccentric, and isometric testing of elbow flexor muscles and to determine test-retest reliability of a specific isokinetic testing protocol. Thirty healthy women were tested using an isokinetic dynamometer at velocities of 0 degrees, 30 degrees, 120 degrees, and 210 degrees/sec. Reliability was assessed by retesting concentric and eccentric torques at 30 degrees and 120 degrees/sec after a 30-minute rest interval. Mean
eccentric peak torque was greater than either isometric or concentric peak torque; as isokinetic test velocity increased, the differences between concentric and eccentric torques became larger. Intraclass correlation coefficients ranged from 0.72 to 0.83, indicating lack of consistency between test and retest torques. Consecutive concentric-eccentric testing and lack of mechanical stabilization might have contributed to test-retest variability and to the relatively small differences between concentric and eccentric torques.

Ellenbecker et al. (2003) conducted a study to determine whether bilateral differences exist in concentric elbow flexion and extension strength in elite junior tennis players. Thirty-eight players were bilaterally tested on a cybex 6000 isokinetic dynamometer at 90°/s, 210°/s and 300°/s. Results showed significantly greater \((P<0.002)\) dominant arm elbow extension peak torque values at 90°/s, 210°/s and 300°/s for males. Significantly greater \((P<0.002)\) dominant arm single repetition work values were also measured at 90 degree/sec, 210 degree/sec for males. No significant difference was measured between extremities in elbow flexion muscular performance in males and for elbow flexion or extension peak torque and single repetition work values in females. No significant difference between extremities was measured in elbow flexion/extension strength ratios in females and significant difference between extremities ratio were only present at 210 degree/sec in males \((p<0.02)\). These data indicated muscular adaptations around the dominant elbow in male elite junior tennis players but not in females.

2.1.4. Wrist and Forearm Strength

Ellenbecker et al. (2006) determined whether there are laterality differences in wrist extension/flexion \((E/F)\) and forearm supination/pronation \((S/P)\) strength in elite female tennis players aged 12 to 16 years with no history of upper extremity injury, underwent bilateral isokinetic testing using a Cybex 6000 dynamometer. Peak torque and single repetition work values for wrist extension/flexion and forearm supination/pronation were measured at speeds of 90°/s and 210°/s, with random determination of the starting extremity. Repeated measures analysis of variance was used to determine differences between extremities for peak torque and single repetition work values.
Results showed significantly greater dominant arm wrist extension/flexion and forearm pronation strength was at both testing speeds. Significantly less dominant side forearm supination strength was measured at both testing speeds. Greater dominant arm wrist extension/flexion and forearm pronation strength is common and normal in young elite level female tennis players. These strength relations indicated sport specific muscular adaptations in the dominant tennis playing extremity. The results of the study could guide clinicians who worked with young athletes from that population. Restoring greater dominant side wrist and forearm strength was indicated after an injury to the dominant upper extremity in such players.

**2.1.5. Hip Strength**

Burnett *et al.* (1990) conducted a study to determine the reliability of measurements of hip muscle torque obtained with the Cybex II isokinetic dynamometer from healthy young boys. Twenty-nine healthy boys, aged 6 to 10 years, were tested two times at one- to two-week intervals. Torque of the hip flexors and extensors and the hip abductors and adductors was assessed at angular velocities of 30 degrees and 90 degrees/sec. The torque generated by each muscle group at 30\(^\circ\)/s was similar to the torque generated at 90\(^\circ\)/s. Intra-class correlation coefficients (ICCs) were used to determine test-retest reliability for measurements of each of the muscle groups at both angular velocities. The ICCs were higher for hip flexion and extension than they were for hip abduction and adduction. The highest ICC (ICC = 0.84) was found for hip extension at 90\(^\circ\)/s. The ICCs for hip abduction and adduction at both angular velocities were < 0.60.

Blazevich *et al.* (1998) tested and compared well-trained athletes who were performing low-velocity, high-force resistance training and sprint running training when recruited, with subjects who were performing low-velocity, high-force resistance training but not sprint training when recruited. Eleven male sprint runners (mean age = 19.0 ± 1.4 year), and eight male weight-trained athletes who were not currently performing sprint training, or any other additional training, (mean age = 21.5 ± 1.8 year) participated in the study. All subjects had a minimum of two years resistance training.
experience. Tests included 1. running speed (20 m time after a 50 m acceleration distance and 20 m acceleration time from a stationary start), 2. isokinetic hip flexor/extensor torque (and torque adjusted for body mass), angle of peak torque, time to reach peak torque and torque acceleration energy at low (60°/s), moderate (270°/s) and high (480°/s) speeds and 3. maximum squat lift. The results of the study suggested that athletes who had performed low-velocity, high force training concurrently with high-velocity training were superior in tests of isokinetic strength at high velocities when compared to athletes who only performed low-velocity, high force training. This difference might be due to training or genetic effects.

Lanning et al. (2006) measured trunk endurance and hip strength in a population of National Collegiate athletes (n=105). The series of tests included the 60-second back-extension endurance and 60-second tall-kneeling tests. A handheld dynamometer was used to measure maximal hip external rotation strength bilaterally. The double-leg lowering test was measured in degrees, and the Star Excursion Balance Test was measured in four directions as a percentage of the subject's leg length. The average score for the 60-second back-extension endurance test was 53 ± 13 repetitions. The 60-second tall-kneeling test had an average score of 30 ± 8 repetitions. For the 2 hip external-rotation strength tests, the average score was 7 ± 4 kg (12% of body weight). Average scores were 50° ± 10° for the double-leg lowering test and 94 ± 9 cm (105% of leg length) for the Star Excursion Balance Test. The descriptive data from these trunk and hip tests allowed for the development of baseline values for each test.

Claiborne et al. (2009) studied test-retest reliability of isokinetic hip torque and electromyogram (EMG). Thirteen healthy young adults participated in two experimental sessions, separated by approximately one week. During each session, isokinetic hip torque was evaluated on the Biodex Isokinetic Dynamometer at a velocity of 60°/s. Subjects performed three maximal-effort concentric and eccentric contractions, separately, for right and left hip abduction/adduction, flexion/extension, and internal/external rotation. Surface EMGs were sampled from the gluteus maximus, gluteus medius, adductor, medial and lateral hamstring, and rectus femoris muscles during all contractions. Motions that demonstrated high torque reliability included.
concentric hip abduction, flexion, extension (right) and internal rotation, and eccentric hip abduction (left), adduction (left), flexion (right), and extension (ICC range=0.81-0.91). Motions with moderate torque reliability included concentric hip adduction (right), extension (left), internal rotation (left), and external rotation (right), and eccentric hip abduction and adduction (right), flexion (left), internal rotation (right and left), and external rotation (right and left) (ICC range=0.49-0.79). The majority of the EMG sampled muscles (n=12 and n=11 for concentric and eccentric contractions respectively) demonstrated high reliability (ICC=0.81-0.95). Instances of low, or unacceptable, EMG reliability values occurred for the medial hamstring muscle of the left leg (both contraction modes) and the adductor muscle of the right leg during eccentric internal rotation. The major finding revealed high and moderate levels of between-day reliability of isokinetic hip peak torque.

Ford et al. (2013) determined the relationship between hip isokinetic strength and thorax and pelvic motion during treadmill running in 24 collegiate cross-country runners (14 males and 10 females). Each subject completed a running protocol on a treadmill at a self-selected speed (3.58 ± 0.26 m·s) and prescribed speed (3.58 m·s). Kinematic data were collected with retro-reflective markers attached to the thorax, pelvis, and each lower extremity segment (thigh, shank, and foot). Thorax and pelvis range of motion (ROM) were calculated from initial ground contact to toe-off. Pearson’s correlation coefficients were used to determine the relationship between strength and ROM (P<0.05). Differences between male and female athletes were tested with mixed-design ANOVAs (P<0.05). Moderate correlations were found in hip extensor and hip abductor strength and pelvic and thorax motion during running in collegiate runners.

Alexander (1990) conducted a study to provide descriptive strength estimates of the major muscle groups of the lower limbs (hip, knee, and ankle joints) for a group of elite sprinters by comparing both the eccentric and concentric and the agonist and antagonist peak torques. These values were measured both eccentrically and concentrically for each of the joint movements tested, using a Kin/Com isokinetic dynamometer. The peak torque values for the knee joint were found to be substantially
larger than those reported for non-athletes, and comparable to those for other athletic populations. No comparable scores were observed for the results of the hip and ankle scores. The flexion and extension ratios for the knee joint at approximately 0.60, whereas the ratios for the hip joint were larger at 0.76. The concentric and eccentric ratios varied, depending on the speed of testing and the joint tested.

Paul et al. (1997) conducted a study to establish the relationship between the flexor/extensor torque ratios in the hip, knee, and ankle. 138 subjects completed all the tests in concentric mode, and 65 in eccentric mode. The flexor/extensor torque ratios of the hip, knee, and ankle were analyzed by means of isokinetic concentric and eccentric tests. Analysis of variance was carried out to compare the mean values of the ratios obtained between the male and female populations and between the right and left sides, and correlation analysis between the values of the joints. The flexor/extensor torque ratios differed significantly according to sex and angular velocities, but not according to side except for the ankle. No significant relationship was found between the flexor/extensor torque ratios in the hip, knee, and ankle joints. The study concluded that flexor-extensor torque ratio of the knee and hip could be used as a reference point during rehabilitation of the contralateral side.

Burchanan et al. (2009) conducted a study to determine lower-extremity strength profiles and gender-based classification of basketball players ages 9-22 years. Fifty basketball players (26 females, 24 males) performed concentric isokinetic testing of bilateral hip, knee, and ankle musculature. Study analysed maximal peak torque. Mean values were typically higher for older vs. younger players and for male vs. female players. Mean values were often lower for girls 12-13 years vs. those 9-10 years. In the age group of 16-22 years, males had stronger knee flexors, hip flexors, plantar flexors, and total leg strength than females. Males who were 16-22 years old had stronger knee flexors and hip flexors than did younger male and female players. Based on discriminant function, knee strength measures did not adequately classify gender. Instead, total leg strength measures had correct gender classifications of 74 and 69% with significant multivariate tests (p = 0.025). These results support strength assessment and training of the whole lower extremity, not just knee musculature. Limited strength
differences between girls of 9-10 years old and those of 12-13 years old suggested that the peripubertal period is an important time to target strength development.

2.1.6. Knee Strength

Nutter et al. (1987) examined the relative importance of body size and composition as determinants of individual differences in isokinetic leg extensor strength in young adult males performing at slow, moderate and fast speeds. The subjects were 31 males between the ages of 19 and 29 years. Low to moderate correlations were found between isokinetic strength and body size or body composition measurements. At each speed, similar proportions of the variance in peak torque values were accounted for by lean body weight (23-30%) and thigh volume (20-37%). However, body weight, often suggested as the best reference standard for equalizing strength scores, also accounted for only 13-24% of the variance in peak torque values at each of the speeds tested. The moderate correlations reported in this study do not support the use of body size and composition measurements as a means of adjusting strength values.

Read et al. (1990) studied the comparison of hamstring/quadriceps isokinetic strength ratios and power in tennis, squash, and track athletes. Isokinetic assessment of athletes confirmed the accepted ratio of 60 to 80 per cent hamstring to quadriceps when testing at 90 deg/sec. for peak strength (torque). However, significant variations occur at higher test speeds up to 300 deg/sec with the hamstrings becoming more prominent especially ($p < 0.001$) in the non-preferred leg. There was no significant differences between various sports. Analysis of power showed a significantly higher work output ($p < 0.01$) by track athletes than squash and tennis players, but, unlike hamstring/quadriceps ratio, no significant difference between preferred and non preferred leg. The maximum power output was achieved around 220 to 2500/s. Power between preferred and non-preferred legs was the same but the torque ratio differed indicating that the hamstrings provided proportionately more work in the non-preferred leg at higher speeds.

Anderson et al. (1991) conducted a study to compare the relationships among isometric, isotonic and isokinetic concentric and eccentric quadriceps and hamstring forces and three components of athletic performance in collegiate male athletes.
Bilateral quadriceps and hamstring muscle torque were obtained (N=39) using a kincom for concentric (rate at 60°/s and 180°/s) eccentric (rate at 30°/s and 90°/s), isotonic and isometric (knee angle at 60°) contractions. Athletic performance was assessed using vertical jump performance, 40-yard dash time and agility run time. The best predictor of 40-yard dash time was the right peak isokinetic concentric hamstring force at 60°/s (r =0.57; P<0.05). The best predictor of agility runtime was the left mean isokinetic eccentric hamstring force at 90 degree/sec(r = 0.58; P<0.05). There were no significant correlation between any quadriceps or hamstring force and vertical jump. It was concluded that isokinetic eccentric quadriceps and hamstring forces were no better predictors of athletic performance than muscle forces assessed in other ways. However, they may be more predictive of some specific components of performance.

McCleary et al. (1992) conducted a study to estimate the reliability of reciprocal concentric knee extension and flexion peak torque obtained in uninjured male athletes using the Biodex isokinetic dynamometer. Twenty-six male intercollegiate athletes (mean age=19.5±4.1 years) participated in this study. Intra-class correlation coefficients (ICCs) ranged from 0.88 on trial 1, day 1 for both extension and flexion peak torque to 0.97 for extension peak torque and 0.98 for flexion peak torque on day 3, trial 6. The standard error of measurement for extension peak torque was 7.0 ft-lbs and for flexion peak torque was 3.0 ft-lbs. These results indicate that reliable measurements of reciprocal right knee extension and flexion peak torque can be obtained from uninjured male athletes with the Biodex isokinetic dynamometer.

Woodson et al. (1995) has analyzed the relationship of peak torque with work and power on the muscles surrounding the knee with correlation coefficients being reported, ranging from 0.67 to 0.99. No studies to date have examined this relationship for muscles surrounding the ankle joint. The purpose of this study was to analyse the relationship of peak torque with work and power for the plantar flexor and dorsiflexor muscles of the ankle. Isokinetic data were collected from 15 healthy subjects (six males, nine females; mean age ± 26.6 years) on an isokinetic dynamometer across two trials at speeds of 30 and 120 degrees/sec. The results of Pearson’s product moment correlations between peak torque to work and peak torque to power indicated correlation
coefficients ranging from 0.81 to 0.97 for all speeds of testing and angular velocities. These findings suggested that peak torque was representative of work and power.

Housh et al. (1996) conducted a study to examine the covariate influence of fat-free weight (FFW) on age-related increases in isokinetic peak torque for leg (knee) flexion and extension in high school female gymnasts. Seventy-two gymnasts (mean age 15.7 ± 1.2 years) volunteered to be measured for isokinetic leg flexion and extension strength using a calibrated Cybex II dynamometer at 30°/s, 180°/s, and 300°/s as well as for body composition from underwater weighing. The results indicated that for the high school female gymnasts, there were age-related increases in strength that could not be accounted for by changes in FFW. It is possible that factors such as an increase in muscle mass per unit of FFW and/or neural maturation contributed to increase in strength during adolescence in female athletes.

Lindle et al. (1997) assessed age and gender comparisons of muscle strength in 654 women and men aged 20-93 years. Peak torque was measured in the knee extensors at a slow (30°/s) and fast (180°/s) velocity in 654 subjects (346 men and 308 women, aged 20-93 years) from the Baltimore Longitudinal Study of Aging. Both men and women showed significant declines in muscle quality for concentric peak torque (P < 0.01), but no gender differences were observed. Only the men showed a significant decline in muscle quality (P < 0.001) for eccentric peak torque. Thus both men and women experienced age-related losses in isometric, concentric, and eccentric knee extensor peak torque; however, age accounted for less variance in eccentric peak torque in women, and women tend to better preserve muscle quality with age for eccentric peak torque. In addition, older women have an enhanced capacity to store and utilize elastic energy compared with similarly aged men as well as with younger women and men.

Pincivero et al. (1997) studied the effects of rest interval on isokinetic strength and functional performance after short-term high intensity training. Fifteen healthy collegiate individuals were randomly assigned to either a short rest interval group or a long rest interval group. Subjects were evaluated for quadriceps and hamstring isokinetic strength at 60°/s (five repetitions) and 180°/s (30 repetitions) and functional performance with the single leg hop for distance test. One leg of each subject was
randomly assigned to a four week, three days/week isokinetic strength training programme for concentric knee extension and flexion performed at 90 degrees/second. Subjects in group of short rest interval received a 40 second rest interval in between exercise sets, whereas subjects in group of long rest interval received a 160 second rest period. A two factor analysis of variance for the pre-test–post-test gain scores (%) showed significantly greater improvements for isokinetic hamstring total work and average power at 180 degrees/second for the trained limb of subjects in group long rest interval than their contralateral non-trained limb and the subjects in group short rest interval. Significantly greater improvements for the single leg hop for distance were also found for the trained limbs of subjects in both groups as compared with the non-trained limbs. The findings indicate that a relatively longer intra-session rest period resulted in a greater improvement in hamstring muscle strength during short term high intensity training.

Kelis et al. (2001) examined the effects of age, velocity and leg of preference on the peak moments in young soccer players. One hundred and fifty eight soccer players (mean age = 13.2 ± 2.1 years) performed maximum knee extension and flexion efforts at 30°/s, 90°/s, 120°/s and 180°/s of both legs and under eccentric and concentric conditions. The isokinetic moment of force of knee extensors ranged from 1.01 ± 0.19 to 3.58 ± 0.50 Nm/kg. The knee flexion moments ranged from 0.95 ± 0.16 to 2.42 ± 0.59 Nm/kg. For all testing conditions eccentric moments were greater than the corresponding concentric moments (p<0.05). The isokinetic moment under all testing conditions increased significantly (p<0.05) as chronological age increased from 10 to 18 years. Furthermore, the isokinetic moment of the preferred leg, collapsed for the effects of age, angular velocity and muscle action, was significantly greater compared to the moments of the other leg. The strength profiles developed in the present study can assist in the establishment of baseline data in young soccer players.

Marc et al. (2001) conducted a study to define the test-retest reproducibility for measuring the peak torque of the knee flexors according to the isokinetic concentric and eccentric muscle action. The tests were done in two sessions at a 21 day interval. Ten healthy national-level volleyball players (mean age 24.3 ± 3.9 years) were included. Evaluation was carried out with a Cybex 6000 dynamometer and the reliability was
calculated according to the intra-class correlation coefficient (ICC~2.1). The protocol consisted of 5 isokinetic concentric contractions at 180°/s followed by 5 isokinetic eccentric contractions at 30°/s and 60°/s. Results showed an excellent reproducibility for isokinetic concentric peak torque at 180°/s. (ICC: 0.94) and very good reproducibility for isokinetic eccentric peak torque at 30°/s and 60°/s. (ICC: 0.86; 0.83). These results indicated that knee flexion strength at these velocities might be used to estimate the performance of volleyball players.

Rosene et al. (2001) compared the differences in the concentric hamstrings: quadriceps (H:Q) ratio among athletes in different sports at 3 velocities. The H:Q ratio of both knees were measured using the Biodex Pro Isokinetic Device. Eighty-one (male and female) collegiate athletes were included. To compare the means of the concentric H:Q ratios for mean peak torque and mean total work, a mixed-factorial analysis of variance was computed for women and a mixed-factorial analysis of variance was computed for men. There was no significant interactions for men and women for the concentric H:Q ratio for mean peak torque. There was a significant mean difference among velocity conditions and a significant difference for men with respect to velocity. No significant differences were found for side of body or sport. The H:Q ratio increased as velocity increased. No differences existed for the H:Q ratio for sport or side of body.

Marinho et al. (2002) conducted a study to dynamically evaluate, through isokinetic tests, the peak torque, total work, and average power of the knee flexor and extensor muscles of athletes (jumpers and runners) and compare them to those of a non-athletic population, evaluating dominance and balance between agonistic and antagonistic muscle groups. Results of the study suggested that in the non-athlete group, there was higher asymmetry between the dominant and non-dominant members. The jumpers had the highest values of the evaluated parameters of all groups, whereas parameters for the runners were intermediate between non-athletes and jumpers.

Buchanan et al. (2003) assessed hamstrings and quadriceps strength of basketball players ages 11–13 and 15–17 years. The cross-sectional study occurred during the 2000 American Youth Basketball Tour National Tournament. We investigated whether sex- or age-related strength differences existed among the participants. Forty-one tournament participants (22 girls, 19 boys) who reported no
history of knee sprain or surgery were recruited. We used a Cybex II dynamometer to obtain isokinetic concentric peak torques relative to body mass (Nm/kg) at 608/s for hamstrings and quadriceps bilaterally. From average peak torques, we determined ipsilateral hamstrings: quadriceps and homologous muscle-group ratios. Correlations between hamstrings and quadriceps strength measures ranged from 0.78 to 0.97. Players aged 15–17 years had greater relative hamstrings and quadriceps strength than 11- to 13-year-old athletes. Age and sex interacted significantly for quadriceps strength. The quadriceps strength of 15 to 17 year girls did not differ from that of 11 to 13 year girls, whereas 15 to 17 year boys had stronger quadriceps than 11 to 13 year boys. Boys aged 15–17 years had greater quadriceps strength than girls of 15–17 years. This study was unique in providing normative data for the hamstrings and quadriceps strength of basketball players aged 11–13 and 15–17 years. Age-related strength differences did not occur consistently between the sexes, as girls 11–13 and 15–17 years had similar relative quadriceps strength.

Harrison et al. (2004) examined the torque-velocity and power-velocity relationships of quadriceps muscle function, stretch shortening cycle function, and leg-spring stiffness in sprint and endurance athletes. Isokinetic maximal knee extension torque was obtained from 7 sprinters and 7 endurance athletes using a Contrex isokinetic dynamometer. Torque and power measures were corrected for lean-thigh cross-sectional area and lean-thigh volume, respectively. Stretch-shortening cycle function and muscle stiffness measurements were obtained while subjects performed single-legged squat, counter-movement, and drop-rebound jumps on an inclined sledge and force-plate apparatus. The results indicated that sprinters generated, on average, 0.15 ± 0.05 N.m.cm(-2) more torque across all velocities compared with endurance athletes. Significant differences were also found in the power-velocity relationships between the two groups. The sprinters performed significantly better than the endurance athletes on all jumps, but there were no differences in pre-stretch augmentation between the groups. The average vertical leg stiffness during drop jumps was significantly higher for sprinters (5.86 N/m) compared with endurance runners (3.38 N/m). The findings reinforced the need for power training to be carried out at fast contraction
speeds but also showed that stretch-shortening cycle function remained important in endurance running.

Koutedekis et al. (2004) assessed the effects of 12 weeks of quadriceps and hamstring strength training on torque levels after a dance exercise and on selected anthropometric parameters. The sample consisted of 22 (mean age, 25 ± 1.3 years) full-time professional ballerinas who were randomly assigned into experimental (n = 12) and control (n = 10) groups. A dance routine designed to cause fatigue within 5 minutes, isokinetic dynamometry, and anthropometric assessments were conducted before and after strength training in both groups. Before strength training, the dance routine resulted in significant reductions of hamstring (p < 0.001) and quadriceps (p < 0.001) peak torques in both the subject groups. However, after strength training, only control subjects demonstrated such torque decrements (p < 0.001) after the dance routine. Furthermore, the experimental group revealed greater knee extension (119 vs. 138 N.m; p < 0.001) and flexion (60 vs. 69 N.m; p < 0.001) torques, smaller sum of skinfolds (33.6 vs. 27.8 mm; p < 0.01), more fat-free mass (37.7 vs. 39.4 kg; p < 0.05), but unchanged body mass (p > 0.05) and thigh circumferences (p > 0.05). A negative relationship (p < 0.001) was found between initial strength levels and improvements measured at the end of the 12-week program. These results suggested that supplementary strength training for hamstring and quadriceps muscles was beneficial to professional ballerinas and their dancing; weaker individuals are more likely to benefit from such regimens than their stronger counterparts, whereas increases in thigh-muscle strength did not alter selected aesthetic components.

Olmo et al. (2005) studied explosive strength-related isokinetic parameters in 65 high-level sprinters and 41 long-distance runners, performed maximal isokinetic knee flexion/extension exertions at 60°/s and 300°/s using the dominant limb. Multiple strength parameters of hamstrings and quadriceps were studied including peak torque (PT) at both velocities, %PT at 0.2 s of contraction initiation at 60°/s, average explosive work at 300°/s, average power at 300°/s and Relative Power Index - RPI. The only parameter which did not significantly correlate with peak torque 60°/s was the RPI in both flexion and extension. Irrespective of gender, this parameter was also significantly
higher in sprinters compared with long-distance runners, and higher in the hamstrings than in the quadriceps. Therefore the use of this parameter was recommended for measuring explosive strength related to sprinting performance in the athletes.

Olmo et al. (2006) conducted a study to determine optimal parameters for representing knee flexion and extension strength in athletes and described reference values for track and field athletics, 248 high-level Spanish athletes of 22 different specialties and a group of 68 sedentary subjects were tested isokinetically at 60 and 300°/s. Absolute and weight normalized strength of the flexors and extensors as well as the hamstrings/quadriceps ratio (H/Q60, H/Q300) were studied. Significant correlations were found among all flexion and extension and between the H/Q ratios. Comparative analysis revealed significant differences among groups for the strength at 60°/s and largely no differences in the H/Q ratio. It was concluded that for discriminating between groups the peak torque at 60°/s was sufficient. Moreover as the athletic specialty had no effect on the H/Q ratio its use for this particular purpose should be discontinued.

Meric et al. (2007) conducted a study to determine knee flexibility and knee isokinetic performance of soccer players who play in different positions. Nineteen professional soccer players who play in Kocaelispor were chosen as a subject. Range of motion of knee and the knee flexion/extension muscle strengths were measured at 60, 180 and 300 deg/sec con-con angular velocity protocol using biodex system III dynamometer. Statistically significant difference of total work of knee extensor in 60°/s was found between forwards and midfielders and also between forwards and defenders (p<0.05). Extensor muscle strength of forwards less than which of defenders and which of midfielders. Statistical differences were shown in 60°/s Peak torque/body weight of between midfielders and defenders. Defenders have higher extensor muscle strength but lower values ROM. As the muscle strength and volume increased the muscle got shorter. That could make risk for injuries. While an exercise program was prepared, playing positions must be taken into consideration after isokinetic tests. Especially joint flexibility was indicator for future injuries.

Ellenbecker et al. (2007) studied age specific descriptive profile of concentric isokinetic knee extension flexion strength in elite junior tennis players and to determine
whether bilateral differences existed between extremities and across age ranges. A total of 103 elite male tennis players (mean age 15.92 ± 2.14 years) and 53 female tennis players (mean 15.0 ± 2.30 years) were isokinetically tested on a Cybex 6000 isokinetic dynamometer at 180 and 300°/s. Male subjects did show significant (p<0.001) increase in knee extension and flexion strength across the age ranged from 11–15 years to 16–21 years. Female subjects did not show any significant change in the normalized knee extension or flexion strength across age ranges. Hamstring/quadriceps strength ratios were bilaterally symmetric and remained clinically and statistically constant across age ranges for the male and female elite tennis players.

Barber-Westin et al. (2007) studied the effects of age and gender in 1140 athletes, 9 to 17 years old, on muscle strength and neuromuscular control during functional activities. Isokinetic quadriceps and hamstrings strength was measured at 300 deg/s. Limb symmetry was assessed with single-legged hop tests. A video drop-jump test determined lower limb alignment in the coronal plane. They have concluded that maximum hamstrings strength was noted in female athletes by age 11 years, compared with age 14 years in male athletes, and a distinct lower limb valgus alignment existed in the majority of all athletes on landing. The absence of a gender difference in lower limb alignment on landing suggested other factors might be responsible for the gender disparity in knee ligament injury rates.

Hewett et al. (2008) reviewed hamstrings to quadriceps peak torque ratios diverge between sexes with increasing isokinetic angular velocity to determine if females demonstrate decreased hamstrings to quadriceps peak torque (H/Q) ratios compared to males and if H/Q ratios increase with increased isokinetic velocity in both sexes. Twenty-two studies (1967-2004) were included with a total of 1568 subjects (1145 males, 423 females). Males demonstrated a significant correlation between H/Q ratio and isokinetic velocity (r = 0.634, p<0.0001), and a significant difference in the isokinetic H/Q ratio at the lowest angular velocity (47.8±/−2.2% at 30 degrees /s) compared to the highest velocity (81.4±/−1.1% at 360 degrees/s, p<0.001). In contrast, females did not demonstrate a significant relationship between H/Q ratio and isokinetic velocity (R=0.065, p=0.77) or a change in relative hamstrings strength as the speed increased (49.5+/−8.8% at 30 degrees /s; 51.0+/−5.7% at 360 degrees /s, p=0.84). Gender
differences in isokinetic H/Q ratios were not observed at slower angular velocities. However, at high knee flexion/extension angular velocities, approaching those that occur during sports activities, significant gender differences were observed in the H/Q ratio. Females, unlike males, did not increase hamstrings to quadriceps torque ratios at velocities that approached those of functional activities.

Camic et al. (2010) conducted a study to determine the patterns of age-related changes in 1) height (HT), body weight (BW), fat-free weight (FFW), and absolute isokinetic peak torque (PT); and 2) isokinetic PT covaried separately for HT, BW, FFW, and HT and BW combined in young wrestlers. One hundred twenty-five male wrestlers (mean age 14.3 ± 2.4 years) volunteered to perform concentric, isokinetic leg extension and flexion at 180 degrees/sec on a Cybex II dynamometer to measure PT as well as underwater weighing to determine FFW. The results of the study indicated that age-related increase in leg-extension and flexion PT for the current sample of young wrestlers could not be accounted for by changes in HT, BW, FFW, or HT and BW combined. These findings suggested that neural maturation may contribute to increase in leg strength across age in young wrestlers.

Hoshikawa et al. (2010) investigated the event-related differences in the cross-sectional areas and torque generation capabilities of the quadriceps femoris and hamstrings in male high school athletes. Subjects were soccer players (n=32), volleyball players (n=21), rowers (n=29), karate athletes (n=18), sumo wrestlers (n=15), sprinters (n=22), throwers (n=16), and non-athletes (n=20). The cross-sectional areas and quadriceps femoris and hamstrings at the mid-thigh were determined using magnetic resonance imaging. In addition, isokinetic torques during knee extension and flexion were determined at a pre-set velocity of 1.05 rad/s. Cross-sectional areas relative to LBM (2/3) for quadriceps femoris did not differ among the groups, but that for hamstring was higher in sprinters, soccer players, throwers, and karate athletes than in sumo wrestlers, rowers, volleyball players, and non-athletes. Knee extension torque relative to the cross-sectional areas of quadriceps femoris was higher in karate athletes, soccer players, and rowers than in non-athletes, but the corresponding value for knee flexion did not differ among groups. Thus, the study indicated that, at least in male high school athletes, the event-related differences in LBM and the muscularity of quadriceps femoris and hamstrings produced the corresponding differences in the cross-sectional
areas of the reciprocal muscle groups and knee extension and flexion torques, respectively. However, specific profiles related to competitive and/or training styles exist in hamstrings cross-sectional area and knee extension torque, which cannot be explained by the magnitude of LBM and quadriceps femoris cross-sectional area, respectively.

Golic-Perik et al. (2011) investigated the effects of short-term isokinetic training versus isotonic training effects on asymmetry in strength of thigh muscles on the isokinetic performance of athletes. The study was conducted in 38 athletes, (mean age 23.3 ± 3.6 years) participating in national level leagues of different sports, whose initial concentric hamstrings-to-quadriceps (con H/Q) torque ratio was lower than 0.5. During seasonal testing, an isokinetic measurement of knee extensors and flexors was performed at 60°/s. The athletes were divided into two groups. Nineteen athletes performed the isokinetic training protocol (IT) while the second group of 19 athletes followed the isotonic training protocol (RT). Both protocols lasted 4 weeks. After completing the training protocols, both groups underwent a final isokinetic testing. The isokinetic data revealed significant increases after training in measures of peak torque in both extensor and flexor muscle groups, in both the isokinetic training protocol and isotonic training protocol study groups (p<0.05). There were significant increases (p<0.05) in con H/Q ratio in both groups after the implemented protocols, but greater in isokinetic training protocol group. Consequently, applied isokinetic training protocol induced changes in working muscles, thereby restoring detected asymmetry to an acceptable balance more efficiently compared to isotonic training protocol.

Gulin et al. (2011) examined the maximal voluntary peak torques of the quadriceps and hamstring muscles, and the torque ratio between these muscle groups in second division basketball players. Isokinetic peak torques were measured using the Isomed 2000 dynamometer at 60 and 180°/sec. Twenth-three second division basketball players (mean age 22.7 ± 4.14 years) were involved in the study. The normal Hcon/Qcon ratio was 0.60. This ratio has been used to assess thigh muscle imbalance, but the functional con/Qcon ratio was related with velocity of the test it increased above 1.00 with increasing velocity and more extended knee joint positions, it meant the more velocity the more ratio. Physical therapists may use results of the present study in order
to evaluate and plan exercise programs of knee musculature during training and rehabilitation.

Cheung et al. (2012) examined the isokinetic hamstrings-to-quadriceps (H:Q) ratio and bilateral leg strength balance in 40 male college team sport players (mean age: 23.4 ± 2.5 years) (field sport = 23, soccer players; court sport = 17, volleyball and basketball players). Five repetitions of maximal knee concentric flexion and concentric extension were performed on an isokinetic dynamometer at two speeds (slow: 60°/sec and fast: 300°/sec) with 3 minutes rest between tests. Both legs were measured in counter balanced order with the dominant leg being determined as the leg used to kick a ball. The highest concentric peak torque values (Nm) of the hamstrings and quadriceps of each leg were analyzed after body mass normalization (Nm/kg). Court sport players showed significantly weaker dominant leg hamstrings muscles at both contraction speeds (p < 0.05). The H:Q ratio was significantly larger in field players in their dominant leg at 60°/sec (P < 0.001), and their non-dominant leg at 300°/sec (P < 0.001) respectively. Sport-specific leg muscle strength was evident in college players from field and court sports. The results suggested the need for different muscle strength training and rehabilitation protocols for college players according to the musculature requirements in their respective sports.

Joseph et al. (2013) examined variations in maximal torque produced by knee extension, knee flexion, elbow extension, and elbow flexion through a range of joint motion. Subjects were young, healthy men (n = 16) and women (n = 15). Torque was measured isometrically and isokinetically using a modified Cybex apparatus. Isotonic torque was calculated from a one-repetition maximum using a modified N-K device. Joint angles were monitored with an electrogoniometer. Torque-joint angle curves were constructed for both men and women for each muscle group. Isometric torque was highest, followed by isotonic and isokinetic torque. Torque declined with increasing isokinetic velocity. The angle of peak torque was found to be highly variable in individual subjects. Variations in torque curves were explained in terms of mechanical characteristics of the musculoskeletal system. Muscle group capability was generally found to be well matched to the mechanical requirements of the movement.
Abdolhamid et al. (2013) investigated bilateral and unilateral asymmetries of strength and flexibility in male young professional soccer players. Thirty-six soccer players aged 18.9 ± 1.4 years participated in the study. A Biodex Isokinetic Dynamometer was used to assess the hamstring and quadriceps strength at selected speeds of 60°/s, 180°/s and 300°/s. Hip joint flexibility was measured using a goniometer. No difference was observed in conventional strength ratio, dynamic control ratio and fast/slow speed ratio between the dominant and non-dominant legs (p>0.05). All but one of the players (97.2%) had musculoskeletal abnormality (bilateral imbalance > 10%) in one or more specific muscle groups. The dominant leg had greater hip joint flexibility compared with the non-dominant leg (108.8 ± 10.7° versus 104.6 ± 9.8°, respectively). The findings supported the hypothesis that physical performance and movement pattern experienced during soccer playing might negatively change the balance of strength in both legs (bilateral strength balance), but not on the same leg of the young male professional soccer players. The results could be helpful for trainers and coaches to decide whether the players needed to improve their balance and strength which in turn might prevent injury.

2.1.7. Ankle Strength

So et al. (1994) studied the isokinetic characteristics of the ankle (plantar-flexion and dorsiflexion) in young men. Six cyclists, seven gymnasts, 10 soccer players and 25 non-athletic young men were tested on the Cybex II+ dynamometer. Peak torque, torque acceleration energy (TAE), total work and average power were measured. Cyclists had slightly higher (5%) mean plantar flexion than the others. The situation was reversed for dorsiflexion. Moreover, the average dorsiflexion per unit of plantar flexion was significantly (p<0.05) higher in the gymnasts than it was in the cyclists for both torque and work. The non-athletic subjects had substantially lower endurance capability in both flexors as measured by the endurance ratio. This implies that identifiable specialization in particular muscles resulted from training or participating in specialized sports.

Serap-Habib et al. (2012) observed the isokinetic muscular strength differences of the ankle-foot complex of sprinters of both sexes to understand the effectiveness of
the ankle and subtalar range of motion on the sprint performances of elite athletes. Elite Turkish national sprinters (n = 11; 5 females and 6 males) were assessed regarding their ankle joint isokinetic performance (30°/s and 120°/s), joint ranges, and sprint times. A significant difference was observed between the average power of the right dorsiflexors (p < 0.001) of female athletes and the right invertors (p < 0.05) of male athletes at 120°/s for the 100-m sprint time. The average powers of the right (p < 0.05) and left (p < 0.05) evertors of the male athletes at 30°/s were significantly negatively correlated with sprint time. Additionally, only the plantar flexion range was significant for male athletes sprint times, and the dominant invertors peak torque at 120°/s in female athletes was significant (p < 0.05). The strength of the non-dominant side dorsiflexors of female athletes and the non-dominant invertors of male athletes are important in decreasing the strength asymmetry to disregard the strength of the non-dominant side in relation to sprint performance.

2.2. Anthropometry

Viitasalo et al. (1985) studied maximal isometric muscular strength and anthropometric characteristics were studied among three random samples (31–35, 51–55 and 71–75 years) each containing about 180 Finnish men with a mean age of 32·9 ± 1·4, 53·1 ± 1·5 and 72·7 ± 1·4 years respectively. Strength was measured on dynamometers for grip, trunk and knee extension and trunk and elbow flexion. The anthropometric characteristics included height, weight, body mass index, skeletal weight, fat weight and a weight factor. The youngest cohort had the highest and the oldest cohort the lowest values for strength as well as body height and fat-free body weight, while the middle-aged group had the highest and the youngest group the lowest values for body weight, fat weight, body mass index and for the weight factor. In correlation, analysis grip strength was found to have the highest correlation with chronological age and to be least affected by the body anthropometric variables among the strength variables studied. On a percentage scale, the decline of strength from the youngest to the oldest cohort was in the order: knee extension (47%), hand grip (42%), trunk extension (42%), trunk flexion (35%) and elbow flexion (35%). The body-mass index was found to be an important variable to be controlled in studying differences between age groups in muscle strength.
Fuster et al. (1998) studied 303 students from the Complutense University at Madrid (100 males and 203 females), aged between 21 and 29 years, the results of nine anthropometric measurements and four strength tests were evaluated. Males and females were analyzed separately in order to determine whether the relationship of body typology to physical performance varies according to gender. Regarding strength, maximum gender differences were observed for pulling strength (females: 53% of male values), followed by hand grip (59%) and vertical jump (66%). In general, correlations among variables were significant (anthropometric, strength, and anthropometric/strength). Principal component analysis revealed, that for women the vertical jump could be interpreted as more dependent on trunk length than on height or body size. Body size was relevant with respect to static strength. For males the vertical jump appeared to be more related to longitudinal dimensions than for females, while static strength had more to do with body mass (weight) than with body size (height).

Niels Uth (2005) compared the anthropometry of sprinters and people belonging to the normal population. The height and body mass (BM) distribution of sprinters (42 men and 44 women) were statistically compared to the distributions of American and Danish normal populations. The main results showed that there was significantly less body mass and height variability (measured as standard deviation) among male sprinters than among the normal male population (US and Danish), while female sprinters showed less body mass variability than the US and Danish normal female populations. On average, the American normal population was shorter than the sprinters. There was no height difference between the sprinters and the Danish normal population. All female groups had similar height variability. Both male and female sprinters had lower body mass index than the normal populations. It was likely that there was no single optimal height for sprinters, but instead there was an optimum range that differs for males and females. This range in height appeared to exclude people who were very tall or very short in stature. Sprinters were generally lighter in body mass than normal populations. Also, the BM variation among sprinters was less than the variation among normal populations.

Almuzani (2007) determined isokinetic strength and endurance, isometric strength, and anaerobic power for untrained healthy Saudi children and adolescents. The
secondary purpose was to evaluate the effects of age in relation to anthropometric characteristics on strength and anaerobic performances. Forty-four (untrained) 11 to 19 year old boys were grouped by age: 11–13 years, 14–16 years, and 17–19 years. All participants underwent anthropometric measurements, a flexibility test, a vertical jump test, a grip strength test, isokinetic strength measurements, and a Wingate anaerobic power test. Results indicated age-related increases in muscle strength and power. High correlation coefficients that were found among age and strength and anaerobic power indices almost disappeared when fat-free mass (FFM) was controlled for, indicating that the amount of variance in these indices that was explained by age is mostly shared by FFM. In addition, stepwise linear regression models indicated that FFM was the main predictor of strength and power performances. Thus, FFM was the best scaling variable for body size when comparing these age groups of Saudis. Until wide-range normal representative values for isokinetic strength and anaerobic power for Saudi children and adolescents were available, the findings of the study could serve as a reference for these indices.

Tsolakis et al. (2010) investigated the differences in selected anthropometric, strength-power parameters and functional characteristics of fencing performance between elite and sub-elite fencers. Thirty-three fencers (18 female and 15 male) from the Greek National Team, (age 19 ± 3.5 years) were classified as elite and sub-elite, according to their international experience. Subjects underwent a detailed anthropometric assessment and performed selected leg power and fencing specific tests. Significant differences were observed between the two groups in sitting height, triceps, subscapular, and quadriceps dominant skinfold thickness, absolute and body mass-dependent expressions of leg functional power characteristics of fencing performance: “time of lunge” and time of the “shuttle test”. Anthropometric traits, such as height, body mass, percent fat and limb length were not different among elite and sub-elite fencers. Although technical and tactical factors were good indicators of fencing success, the observed differences in functional fencing performance tests among different levels of fencers were useful for the design of effective talent development and training conditioning programs for competitive fencers.
Ebrahim et al. (2011) examined the relationship between physical parameters measures of the body segments and the 100-meter sprinting performance. Thirty three female subjects aged 19 to 25 years participated in the study. The 100-meter sprinting test was conducted and five physical parameters measures of the body segments, including the thigh length, lower leg length, mid-thigh circumference, calf circumference and ankle circumference were taken. Pearson correlation analysis found that there was no significant relationship between the 100-meter sprinting performance and the selected anthropometric variables (p>0.05). The results suggested that physical parameters of the body segments variables were poor predictors of sprinting performance.

Landers et al. (2011) examined the relationship between stride rate and stride length, with body masses and heights of senior elite triathletes during the run stage of a triathlon. The stride rate and stride length of 37 male senior elite Triathlon World Championships competitors were analysed via videography and Video Expert II Coach. These values were correlated with the athletes body masses and heights (p<0.01). The results indicated a limited relationship between height and mass with stride rate in the early stages of the run. However, a significant, positive correlation existed between stride length and height at all points from 3 km to the end of the run. Those triathletes who were taller used longer strides. Further research is warranted to examine the effects of cycling on the subsequent run discipline during triathlon and if body size and shape of triathletes have evolved as the young sport of triathlon develops.

Greve et al. (2013) evaluated the relationship between the anthropometric factors of height, body mass, body mass index and postural balance and to compare the balance indices between genders in the upright standing position, in healthy adult subjects under conditions of instability. Forty individuals were subjected to functional tests of body stability using the Biodex Balance System, and the resulting indices were correlated with body mass, height, and body mass index, and also compared between genders. Body mass was the main anthropometric factor that influenced variations in postural balance, with a high correlation between groups and with all variables. A linear regression analysis showed that body mass associated with BMI explained 66% of the overall stability, and body mass explained 59% of the antero-posterior stability index and 65% of the medio-lateral stability index. In the female group, body mass explained
72% of the overall balance, 66% of the antero-posterior, and 76% of the medio-lateral stability index. Increased body mass required greater movements to maintain postural balance. Height and BMI presented moderate correlations with balance. Female showed less movement than male on the Biodex Balance System.

Neto et al. (2013) determined how body composition and anthropometric measures of the lower limb is associated with passive knee extension (PKE) torque-angle (T-A) response. Twenty-five male subjects with poor flexibility performed a maximal PKE repetition (velocity of 2°/s; 90 seconds in the static phase). Knee passive T-A, vastus medialis and semitendinosous electromyographic activity were recorded during the protocol. Viscoelastic stress relaxation (VSR) amplitude, knee passive stiffness (KPS), lower limb body composition assessed by dual energy x-ray absorptiometry, and anthropometry measures were determined. Results of the study showed that the thigh skeletal muscle and bone mass, as well as thigh perimeter, showed a moderate correlation with passive torque Thigh skeletal muscle was also correlated with KPS (r = 0.42). All these correlations were statistically significant (p < 0.05). Passive knee extension T-A was found to be moderately correlated with lower limb body composition.

2.3. Physical Performance Tests

Leger et al. (1988) designed multistage 20 m shuttle run test to determine the maximal aerobic power of schoolchildren, healthy adults attending fitness class and athletes performing in sports with frequent stops and starts (e.g. basketball and fencing). To obtain the regression, the test was performed individually. Right upon termination VO2 was measured with four 20 s samples and VO2max was estimated by retroextrapolating the O2 recovery curve at time zero of recovery. For adults, similar measurements indicated that the same equation could be used keeping age constant at 18 (r = 0.90, n = 77 men and women 18-50 years old). Test-retest reliability coefficients were 0.89 for children (139 boys and girls 6-16 years old) and 0.95 for adults (81 men and women, 20-45 years old).

Cooper et al. (2004) established the validity of a multistage shuttle run test as a predictor of anaerobic capacity (expressed as mean power output (MPO) from the 30
second Wingate anaerobic test in female university standard games players and concluded that the multistage shuttle run test required minimal equipment and training of assessors, and it was easy to perform. In the population studied, it provided scores that were repeatable, and anaerobic capacity (MPO) could be successfully predicted from its performance. It would seem, therefore, to be a useful field based test for use by female games players, their coaches, and support scientists.

Campiello et al. (2013) determined the effects of short-term plyometric training interposed with 24 hours or 48 hours of rest between training sessions on explosive and endurance adaptations in young soccer players. A total of 166 players, between 10 and 17 years of age were randomly divided into 3 groups: control (CG; n=55), plyometric training with 24 h (PT24; n=54), and 48 h (PT48; n=57) of rest between training sessions. Before and after intervention, players were measured in squat jump (SJ), counter-movement jump (CMJ), 20 (RSL20) cm drop jump reactive strength index, broad long jump (BLJ), 20-m sprint time, 10 x 5-m agility time, 20-m multi-stage shuttle run test (MST), and sit and reach test (SR). The plyometric training program was applied during 6 weeks, 2 sessions per week, with a load from 140 to 260 jumps per session, replacing some soccer-specific drills. After intervention, the control group did not show significant performance changes. PT24 and PT48 groups showed a small to moderate significant improvement in all performance tests (p<0.001), with no differences between treatments. Although it was recommended that plyometric drills should not be conducted on consecutive days, the study showed that plyometric training applied twice weekly on consecutive or non-consecutive days resulted in similar explosive and endurance adaptations in young male soccer players.