CHAPTER II

REVIEW OF RELATED LITERATURE

A study of relevant literature is an essential step to get a full picture of what has been done with regard to the problem under study. Such a review brings out a deep and clear perspective of the overall field.

The review of literature is instrumental in selection of the topic, transaction of hypothesis and deductive reasoning leading to the problem. It helps to get a clear idea and support the findings with regard to the problem under study.

The following materials collected from the views expressed by various personalities provide background information to the study and help us to understand the isolated and combined effects of progressive resistance training with pilates training and PNF stretch technique on selected physical, physiological and psychological variables among college level men kabaddi players. The views of the experts and research workers in the field of physical education are given primary importance in the present study.

1. Studies related on Resistance Training
2. Studies related on Pilates Training
3. Studies related on PNF Stretch Technique

2.1 STUDIES RELATED ON RESISTANCE TRAINING

Harries et al., (2012) conducted a study on resistance training to improve power and sports performance in adolescent athletes: a systematic review and meta-analysis. Resistance training in untrained adolescents can positively affect health-related fitness as well as improve muscular power and sports performance. The impact of resistance training on adolescent athletes is less clear. The purpose of this review is to determine the effectiveness of resistance training programs on muscular power and sports performance in adolescent athletes. Systematic review and meta-analysis of previously published studies investigating resistance training in adolescent athlete populations. A systematic search of Medline, Embase, and SPORT Discus
databases was conducted on 21st March 2011 to identify studies evaluating resistance training programs on power and sports performance in adolescent athletes. Thirty-four studies were identified. All but two of the studies reported at least one statistically significant improvement in an alactic muscular power outcome. The most common indicators of alactic power were vertical jump (25 studies) and sprint running (13 studies) performance. Fourteen studies provided data to allow for pooling of results in a meta-analysis. A positive effect was detected for resistance training programs on vertical jump performance (mean difference 3.08 [95% CI 1.65, 4.51], Z=4.23 [P<0.0001]). There is sufficient evidence to conclude that resistance-training interventions can improve muscular power in adolescent athletes. A positive effect on sports performance attributable to participation in resistance training was reported by almost half the included studies, however limited objective evidence to support these claims was found. Improvements in motor performance skills, such as jumping, are widely stated as indicators of improvements in sporting performance.

Grieco et al., (2011) conducted a study on effects of a combined resistance-plyometric training program on muscular strength, running economy, and Vo2peak in division I female soccer players. Resistance and/or plyometric training programs have demonstrated consistent improvements in running economy (RE) in trained and untrained adults in the absence of improvements in maximal oxygen consumption. The purpose of this study was to investigate the effect of a 10-week combined resistance/plyometric training program on RE and VO2max in female soccer players. Fifteen Division 1A female soccer players (19.0 yr ± 0.7; 1.67 m ± 0.1; 61.7 kg ± 8.1) performed a treadmill test for VO2max and RE at the end of a competitive season (PRE) and following a 10-week training program (POST). Isometric strength was measured in knee flexion and extension. Resistance training was conducted 2 days per week on nonconsecutive days; plyometric training was conducted separately on different non-consecutive days. Eleven subjects were included in PRE/POST analysis (19.0 yr ± 0.8; 1.67 m ± 0.5; 59.9 kg ± 6.7). Descriptive statistics were compared using ANOVA with repeated measures with a Bonferroni adjustment and significance was set at p < .05. A significant increase occurred following training in VO2peak.
time-to-fatigue (6.9%; \( p = .017 \)) and interpolated maximal speed (3.6%; \( p = .016 \)), despite a decrease in maximal respiratory exchange ratio (2.9%; \( p = .001 \)). There was no significant change in RE at 9 km*h\(^{-1}\), however, there was a significant decrease in percentage of VO2peak at 9 km*h\(^{-1}\) (-5.6%; \( p = .02 \)). Maximal isometric strength of knee flexors/extensors did not change. The results suggest a plyometric/agility training program may increase VO2peak in female soccer players, however, the effect on RE was equivocal.

**Ignjatovic et al., (2011)** to investigate the influence of additional resistance training on cardio-respiratory endurance in young (15.8 ± 0.8 yrs) male basketball players. Experimental group subjects (n=23) trained twice per week for 12 weeks using a variety of general free-weight and machine exercises designed for strength acquisition, beside ongoing regular basketball training program. Control group subject (n=23) participated only in basketball training program. Oxygen uptake (VO(2max)) and related gas exchange measures were determined continuously during maximal exercise test using an automated cardiopulmonary exercise system. Muscle power of the extensors and flexors was measured by a specific computerized tensiometer. Results from the experimental group (VO(2max) 51.6 ± 5.7 ml.min\(^{-1}\).kg\(^{-1}\) pre vs. 50.9 ± 5.4 ml.min\(^{-1}\).kg\(^{-1}\) post resistance training) showed no change (\( p>0.05 \)) in cardio-respiratory endurance, while muscle strength and power of main muscle groups increased significantly. These data demonstrate no negative cardio-respiratory performance effects on adding resistance training to ongoing regular training program in young athletes.

**Hermassi et al., (2011)** conducted a study on effects of 8-week in-season upper and lower limb heavy resistance training on the peak power, throwing velocity, and sprint performance of elite male handball players, this study were to test the potential of in-season heavy upper and lower limb strength training to enhance peak power output (Wpeak), vertical jump, and handball related field performance in elite male handball players who were apparently already well trained, and to assess any adverse effects on sprint velocity. Twenty-four competitors were divided randomly between a heavy resistance (HR) group (age 20 ± 0.7 years) and a control group (C;
Resistance training sessions were performed twice a week for 8 weeks. Performance was assessed before and after conditioning. Peak power (Wpeak)) was determined by cycle ergometer; vertical squat jump (SJ) and countermovement jump (CMJ); video analyses assessed velocities during the first step (V(1S)), the first 5 m (V(5m)), and between 25 and 30 m (V(peak)) of a 30-m sprint. Upper limb bench press and pull-over exercises and lower limb back half squats were performed to 1-repetition maximum (1RM). Upper limb, leg, and thigh muscle volumes and mean thigh cross-sectional area (CSA) were assessed by anthropometry. W(peak) (W) for both limbs (p < 0.001), vertical jump height (p < 0.01 for both SJ and CMJ), 1RM (p < 0.001 for both upper and lower limbs) and sprint velocities (p < 0.01 for V(1S) and V(5m); p < 0.001 for V(peak)) improved in the HR group. Upper body, leg, and thigh muscle volumes and thigh CSA also increased significantly after strength training. We conclude that in-season biweekly heavy back half-squat, pull-over, and bench-press exercises can be commended to elite male handball players as improving many measures of handball-related performance without adverse effects upon speed of movement.

Molacek et al., (2010) conducted a study to determine the effects of low- and high-volume stretching on bench press performance in collegiate football players, effects of acute low- and high-volume static and proprioceptive neuromuscular facilitation (PNF) stretching on 1-repetition maximum (1RM) bench press. Fifteen healthy male National Collegiate Athletic Association Division II football players (age: 19.9 +/- 1.1 years; weight: 98.89 +/- 13.39 kg; height: 184.2 +/- 5.7 cm; body composition: 14.6 +/- 7.4%; and 1RM bench press: 129.7 +/- 3.3 kg) volunteered to participate in the study. Subjects completed 5 different stretching protocols integrated with a 1RM dynamic warm-up routine followed by 1RM testing in randomly assigned order. The protocols included (a) nonstretching (NS), (b) low-volume PNF stretching (LVPNFS), (c) high-volume PNF stretching (HVPNFS), (d) low-volume static stretching (LVSS), and (d) high-volume static stretching (HVSS). Two and 5 sets of stretching were completed for the low- and high-volume protocols, respectively. The stretching protocols targeted triceps and chest/shoulder muscle groups using 2
There were no significant differences in 1RM bench press performance ($p > 0.05$) among any of the stretching protocols NS (129.7 +/- 3.3 kg), LVVPNFS (128.9 +/- 3.8 kg), HVPNFS (128.3 +/- 3.7 kg), LVSS (129.7 +/- 3.7 kg), and HVSS (128.2 +/- 3.7 kg). We conclude that low- and high-volume PNF and static stretching have no significant acute effect on 1RM bench press in resistance-trained collegiate football players. This suggests that resistance-trained athletes can include either (a) a dynamic warm-up with no stretching or (b) a dynamic warm-up in concert with low- or high-volume static or PNF flexibility exercises before maximal upper body isotonic resistance-training lifts, if adequate rest is allowed before performance.

**Bird et al., (2009)** conducted a study to explore the balance benefits to untrained older adults of participating in community-based resistance and flexibility programs, in a blinded randomized crossover trial, 32 older adults ($M = 66.9$ yr) participated in a resistance-exercise program and a flexibility-exercise program for 16 weeks each. Sway velocity and mediolateral sway range were recorded. Timed up-and-go, 10 times sit-to-stand, and step test were also assessed, and lower limb strength was measured. Significant improvements in sway velocity, as well as timed up-and-go, 10 times sit-to-stand, and step test, were seen with both interventions, with no significant differences between the 2 groups. Resistance training resulted in significant increases in strength that were not evident in the flexibility intervention. Balance performance was significantly improved after both resistance training and standing flexibility training; however, further investigation is required to determine the mechanisms responsible for the improvement.

**Brechue and Mayhew (2009)** conducted a study to assess changes in Upper-body work capacity and 1RM predictions are unaltered by increasing muscular strength in college football players. National Collegiate Athletic Association (NCAA) Division II football players ($n = 58$) were divided into low-strength (LS, 1RM <275 lb, $n = 23$) and high-strength (HS, 1RM > or =275 lb, $n = 35$) groups based on initial 1RM bench press. Maximal repetitions to failure (RTF) were performed with a relative (60, 70, 80, and 90% of 1RM) and absolute load (185 lb for players with 1RM <275 lb; 225 lb for players with 1RM > or =275 lb) at pre- and post-training.
Following training (n = 58), there was a significant increase in 1RM bench press (22.8 +/- 12.0 lb) and body mass (3.7 +/- 10 lb). There was no change in the number of repetitions performed (RTF) during relative load testing following training. However, RTF during absolute load testing was increased. Relative and absolute load work capacity (reps x load) increased with training, but there was no relationship between the change in work capacity and the changes in muscular strength. Predicted 1RM were better at lower repetitions (3-5 RM, >85% 1RM) than at higher repetitions (>6RM, < or =80% 1RM) at both pre-and post-training. In conclusion, changes in muscular strength associated with the off-season training program used herein appear to have little effect on work capacity or prediction of 1RM using sub maximal loads. For repetition predictions to accurately track changes following resistance training, the test load must be relatively high (>85% 1RM) and the repetitions low (< or =5 reps).

Hoffman et al., (2009) conducted a study to examine the Comparison between different off-season resistance training programs in Division III American college football players, efficacy of periodization and to compare different periodization models in resistance trained American football players. Fifty-one experienced resistance trained American football players of an NCAA Division III football team (after 10 weeks of active rest) were randomly assigned to 1 of 3 groups that differed only in the manipulation of the intensity and volume of training during a 15-week offseason resistance training program. Group 1 participated in a nonperiodized (NP) training program, group 2 participated in a traditional periodized linear (PL) training program, and group 3 participated in a planned nonlinear periodized (PNL) training program. Strength and power testing occurred before training (PRE), after 7 weeks of training (MID), and at the end of the training program (POST). Significant increases in maximal (1-repetition maximum [1RM]) squat, 1RM bench press, and vertical jump were observed from PRE to MID for all groups; these increases were still significantly greater at POST; however, no MID to POST changes were seen. Significant PRE to POST improvements in the medicine ball throw (MBT) were seen for PL group only. The results do not provide a clear indication as to the most
effective training program for strength and power enhancements in already trained football players. Interestingly, recovery of training-related performances was achieved after only 7 weeks of training, yet further gains were not observed. These data indicate that longer periods of training may be needed after a long-term active recovery period and that active recovery may need to be dramatically shortened to better optimize strength and power in previously trained football players.

Harrison et al., (2009) conducted a study to demonstrate that the effect of resisted sprint training on speed and strength performance in male rugby players, resistance sprint (RS) training can produce significant changes in running speed and running kinematics. The longer-term training adaptations after RS training remain unclear. The purpose of this study was to investigate whether an RS training intervention would enhance the running speed and dynamic strength measures in male rugby players. Fifteen male rugby players aged 20.5 (+/- 2.8) years who were proficient in resisted sledge training took part in the study. The subjects were randomly assigned to control or RS groups. The RS group performed two sessions per week of RS training for 6 weeks, and the control group did no RS training. Pre- and post intervention tests were carried out for 30-m sprint, drop, squat, and rebound jumps on a force sledge system. A laser measurement device was used to obtain velocities and distance measures during all running trials. The results show a statistically significant decrease in time to 5 m for the 30-m sprint for the RS group (p = 0.02). The squat jump and drop jump variables also showed significant increases in starting strength (p = 0.004) and height jumped (p = 0.018) for the RS group from pre- to post-testing sessions. The results suggest that it may be beneficial to employ an RS training intervention with the aim of increasing initial acceleration from a static start for sprinting.

Dodd et al., (2007) conducted a study on analysis of acute explosive training modalities to improve lower-body power in baseball players; Complex training is the simultaneous combination of heavy resistance training and plyometrics. The objective of this study was to test the effects of complex training vs. heavy resistance or plyometric interventions alone on various power-specific performance measures.
Forty-five male division II junior college baseball players participated in 3 separate 4-week resistance training interventions. Subjects were randomly assigned to one of three groups. In a counterbalanced rotation design, each group participated in complex, heavy resistance, and plyometric training interventions. Each individual was tested in 20-yd (SP20), 40-yd (SP40), 60-yd (SP60), vertical jump, standing broad jump, and T-agility measures pre- and post-4-week training interventions. There was no statistical significant difference (p = 0.11) between groups across all performance measures. Review of each distinct training intervention revealed greater percent improvements in SP20 (0.55; -0.49; -0.12), SP40 (0.26; -0.72; -1.33), SP60 (0.27; 0.15; -0.27), standing broad jump (1.80; 0.67; 1.1), and T-agility (2.33; 1.23; -0.04) with complex training interventions than with the heavy resistance or plyometric training interventions, respectively. Plyometric-only training showed greater percent changes in vertical jump (1.90) than with complex (0.97) or heavy resistance training (0.36). The present results indicate that complex training can provide strength and conditioning professionals equal, if not slightly greater, improvements in muscular power than traditional heavy resistance- and plyometric-only interventions in moderately trained athletes. Complex training can be another valuable method for short-term power and speed improvements in athletes in isolation or in conjunction with other power development methods.

Faigenbaum et al., (2007) conducted a study on preliminary evaluation of an after-school resistance training program for improving physical fitness in middle school-age boys, to evaluate the efficacy of an after-school resistance training program on improving the physical fitness of middle school-age boys. 22 boys (M = 13.9 yr., SD = .4 yr.) participated in a periodized, multiple-set, 9-wk. (2x/week) resistance training program. All subjects were pre- and post-tested on their 10-repetition maximum squat, 10-repetition maximum bench press, vertical jump, medicine ball toss, flexibility, and also percentage of body fat and the progressive aerobic cardiovascular endurance run (PACER). Statistical analysis indicated that subjects significantly improved performance on the squat (19%), bench press (15%), flexibility (10%), vertical jump (5%), medicine ball toss (12%), and the PACER
(36%). Although this design minus a control group limits interpretation, this after-school resistance-training program can improve muscular fitness and cardiovascular fitness in boys and should be replicated with appropriate experimental controls.

Christou et al., (2006) to examine the effects of resistance training on the physical capacities of adolescent soccer players, effects of a progressive resistance training program in addition to soccer training on the physical capacities of male adolescents. Eighteen soccer players (age: 12-15 years) were separated in a soccer (SOC; n = 9) and a strength-soccer (STR; n = 9) training group and 8 subjects of similar age constituted a control group. All players followed a soccer training program 5 times a week for the development of technical and tactical skills. In addition, the STR group followed a strength training program twice a week for 16 weeks. The program included 10 exercises, and at each exercise, 2-3 sets of 8-15 repetitions with a load 55-80% of 1 repetition maximum (1RM). Maximum strength ([1RM] leg press, bench-press), jumping ability (squat jump [SJ], countermovement jump [CMJ], repeated jumps for 30 seconds) running speed (30 m, 10 x 5-m shuttle run), flexibility (seat and reach), and soccer technique were measured at the beginning, after 8 weeks, and at the end of the training period. After 16 weeks of training, 1RM leg press, 10 x 5-m shuttle run speed, and performance in soccer technique were higher (p < 0.05) for the STR and the SOC groups than for the control group. One repetition maximum bench press and leg press, SJ and CMJ height, and 30-m speed were higher (p < 0.05) for the STR group compared with SOC and control groups. The above data show that soccer training alone improves more than normal growth maximum strength of the lower limbs and agility. The addition of resistance training, however, improves more maximal strength of the upper and the lower body, vertical jump height, and 30-m speed. Thus, the combination of soccer and resistance training could be used for an overall development of the physical capacities of young boys.

Hoffman et al., (2003) conducted a study to examine the Strength changes during an in-season resistance-training program for football, effects of both intensity and volume of training during a 2 d.wk(-1) in-season resistance-training program
(RTP) for American football players. Fifty-three National Collegiate Athletic Association Division III football players were tested in the 1 repetition maximum (1RM) bench press and 1RM squat on the first day of summer training camp (PRE) and during the final week of the regular season (POST). Subjects were required to perform 3 sets of 6-8 repetitions per exercise. Significant strength improvements in squat were observed from PRE (155.0 +/- 31.8 kg) to POST (163.3 +/- 30.0 kg), whereas no PRE to POST changes in bench press were seen (124.7 +/- 21.0 kg vs. 123.9 +/- 18.6 kg, respectively). Training volume and training compliance were not related to strength improvement. Further analysis showed that athletes training at >or=80% of their PRE 1RM had significantly greater strength improvements than athletes training at <80% of their PRE 1RM, for both bench press and squat. Strength improvements can be seen in American football players, during an in-season RTP, as long as exercise intensity is >or=80% of the 1RM.

Barbosa et al. (2002) conducted study on effects of resistance training on the sit-and-reach test in elderly women, effects of a 10-week resistance training program on flexibility of elderly women (n = 11) between 62 and 78 years of age. The control group was composed of 8 women (62 to 73 years old) who were physically inactive. Flexibility was evaluated through the sit-and-reach test, performed both before and after the training program. After an initial evaluation, individuals started a training program, which consisted of 8 exercises for the entire body, without the performance of any flexibility exercise. The training program resulted in significant increase (p < 0.001) of flexibility in elderly women (approximately equal 13%). No significant differences were found in the control group. We conclude that weight training without performance stretching exercises does increase flexibility in elderly women.

Esteban et al., (1999) conducted a study to determine the effects of heavy resistance training on maximal and explosive force production, endurance and serum hormones in adolescent handball players, effects of 6-weeks of heavy-resistance training on physical fitness and serum hormone status in adolescents (range 14±16 years old) 19 male handball players were divided into two different groups: a handball training group (NST, n = 10), and a handball and heavy-resistance strength
training group (ST, n = 9). A third group of 4 handball goalkeepers of similar age served as a control group (C, n = 4). After the 6-week training period, the ST group showed an improvement in maximal dynamic strength of the leg extensors (12.2%; P < 0.01) and the upper extremity muscles (23%; P < 0.01), while no changes were observed in the NST and C groups. Similar differences were observed in the maximal isometric unilateral leg extension forces. The height of the vertical jump increased in the NST group from 29.5 (SD 4) cm to 31.4 (SD 5) cm (P < 0.05) while no changes were observed in the ST and C groups. A significant increase was observed in the ST group in the velocity of the throwing test [from 71.7 (SD 7) km h⁻¹ to 74.0 (SD 7) km h⁻¹; P < 0.001] during the 6-week period while no changes were observed in the NST and C groups. During a sub-maximal endurance test running at 11 km h⁻¹, a significant decrease in blood lactate concentration occurred in the NST group [from 3.3 (SD 0.9) mmol l⁻¹ to 2.4 (SD 0.8) mmol l⁻¹; P < 0.01] during the experiment, while no change was observed in the ST or C groups. Finally, a significant increase (P < 0.01) was noted in the testosterone: cortisol ratio in the C group, while the increase in the NST group approached statistical significance (P < 0.08) and no changes in this ratio occurred in the ST group. The present findings suggested that the addition of 6-weeks of heavy resistance training to the handball training resulted in gains in maximal strength and throwing velocity but it compromised gains in leg explosive force production and endurance running. The tendency for a compromised testosterone cortisol ratio observed in the ST group could have been associated with a state of overreaching or overtraining.

2.2 STUDIES RELATED ON PILATES TRAINING

Aladro Gonzalvo et al., (2012) conducted a study to determine the effect of Pilates exercises on body composition: a systematic review, how Pilates exercises have impacted body composition (BC) on selected populations. A comprehensive literature search was performed using the keywords 'Pilates, body composition, systematic review, literature review, overweight, obesity, healthy weight, underweight' and their combination. Seven studies met the inclusion criteria and after further quality analyses it was determined that there is currently poor empirical
quantitative evidence indicating a positive effect of Pilates exercises on BC. Several methodological flaws were observed in the studies analyzed, including few full-text published studies looking into the effects of Pilates exercises on BC, a lack of true experimental research designs, limited standardization in measurement techniques, insufficient or no control of the nutritional status, and inconsistent instructor qualifications. Well-designed research is needed to determine how Pilates exercises impact BC on selected populations.

**Bird et al., (2012)** conducted a study to evaluate the effects of a Pilates intervention on balance and function in community-dwelling older (aged _60y) adults. Ambulatory older community-dwelling adults (N=32) were recruited, and 27 (mean _ SD age, 67.3 _6.5y) completed the program. Participants were allocated to either 5 weeks of a group Pilates training intervention or 5 weeks of usual activity (control). After a 6-week washout period, participants performed the alternate intervention. Static and dynamic balance measures (mediolateral sway range, Four Square Step Test, Timed Up and Go Test) and leg strength were recorded at 4 times before and after each intervention (baseline [t1], interim time immediately after the first group intervention [t2], after 5-week washout [before the second intervention period] [t3], and at study conclusion after the second group intervention [t4]). There were no significant differences between the Pilates and control groups for any measured variables (P_0.05) despite static and dynamic balance significantly improving during the study and from pre- to post-Pilates (P_0.05) without significant changes occurring during the control phase. Improvements that occurred during Pilates between t1 and t2 did not return to baseline after the washout period (t3). There were no changes in leg strength. Mediolateral sway range standing on a foam cushion with eyes closed improved _1.64cm (95% confidence interval, _2.47 to _0.82) and had the largest effect size post-Pilates (d=.72). Although there were no significant between group differences, participation in the Pilates component of the study led to improved static and dynamic balance. The absence of differences between conditions may be a result of small sample size or the crossover study design because Pilates may produce neuromuscular adaptations of unknown resilience.
Alves de Araujo et al., (2011) conducted a study to evaluate the effectiveness of the Pilates method: reducing the degree of non-structural scoliosis, and improving flexibility and pain in female college students, effectiveness of Pilates with regard to the degree of scoliosis, flexibility and pain. The study included 31 female students divided into two groups: a control group (CG Z 11), which had no therapeutic intervention, and an experimental group (EG Z 20), which underwent Pilates-based therapy. We used radiological goniometry measurements to assess the degree of scoliosis, standard goniometry measurements to determine the degree of flexibility and the scale of perceived pain using the Borg CR 10 to quantify the level of pain. The independent t test of the Cobb angle (t Z - 2.317, p Z 0.028), range of motion of trunk flexion (t Z 3.088, p Z 0.004) and pain (t Z _2.478, p Z 0.019) showed significant differences between the groups, with best values in the Pilates group. The dependent t test detected a significant decrease in the Cobb angle (D% Z 38%, t Z 6.115, p Z 0.0001), a significant increase in trunk flexion (D% Z 80%, t Z _7.977, p Z 0.0001) and a significant reduction in pain (D% Z 60%, t Z 7.102, p Z 0.0001) in the EG. No significant difference in Cobb angle (tZ0.430, pZ0.676), trunk flexion, (tZ0.938pZ0.371) or pain (tZ0.896, pZ0.391) was found for the CG. The Pilates group was better than control group. The Pilates method showed a reduction in the degree of non-structural scoliosis, increased flexibility and decreased pain.

Kloubec, (2010) conducted a study to determine the Pilates for improvement of muscle endurance, flexibility, balance, and posture, effects of Pilates exercise on abdominal endurance, hamstring flexibility, upper-body muscular endurance, posture, and balance, Fifty subjects were recruited to participate in a 12-week Pilates class, which met for 1 hour 2 times per week. Subjects were randomly assigned to either the experimental (n = 25) or control group (n = 25). Subjects performed the essential (basic) mat routine consisting of ~25 separate exercises focusing on muscular endurance and flexibility of the abdomen, low back, and hips each class session. At the end of the 12-week period, a 1-way analysis of covariance showed a significant level of improvement (p ≤ 0.05) in all variables except posture and balance. This study demonstrated that in active middle-aged men and women, exposure to Pilates
exercise for 12 weeks, for two 60-minute sessions per week, was enough to promote statistically significant increases in abdominal endurance, hamstring flexibility, and upper-body muscular endurance. Participants did not demonstrate improvements in either posture or balance when compared with the control group. Exercise-training programs that address physical inactivity concerns and that are accessible and enjoyable to the general public are a desirable commodity for exercise and fitness trainers. This study suggests that individuals can improve their muscular endurance and flexibility using relatively low-intensity Pilate’s exercises that do not require equipment or a high degree of skill and are easy to master and use within a personal fitness routine.

**English and Howe, (2007)** conducted a study on the effect of Pilates exercise on trunk and postural stability and throwing velocity in college baseball pitchers: single subject design, effects of the Pilates method of exercise on performance of double leg lowering, star excursion balance test, and throwing velocity in college-aged baseball pitchers. A convenience sample of three college baseball pitchers served as the subjects for this single subject design study. For each subject, double leg lowering, star excursion balance test, and throwing speed were measured prior to the introduction of the intervention. When baseline test values showed consistent performance, the intervention was introduced to one subject at a time. Intervention was introduced to the other subjects over a period of 4 weeks as they also demonstrated consistent performance on the baseline tests. Intervention was continued with periodic tests for the remainder of the 10 week trial. Each subject improved in performance on double leg lowering (increased 24.43-32.7%) and star excursion balance test (increased 4.63-17.84%) after introduction of the intervention. Throwing speed improved in two of the three subjects (up to 5.61%). The Pilates method of exercise may contribute to improved performance in double leg lowering, star excursion balance tests, and throwing speed in college baseball pitchers.

**Jago et al., (2006)** conducted a study on effect of 4 weeks of Pilates on the body composition of young girls. There is a need to find ways to increase the physical activity levels and improve the body composition and blood pressure of girls. Thirty
11-year-old girls were recruited from two after school programs in Houston Texas in spring 2005. Participants from one program (16) were randomly assigned to intervention, the other (14) served as controls. BMI, BMI percentile, waist circumference and blood pressure were assessed before and after the intervention. Pilates classes were provided free of charge for an hour per day at the intervention site, 5 days a week, for 4 weeks. Four participants wore heart rate monitors during every session and completed enjoyment and perceived exertion questionnaires. Repeated measures analysis of variance with time (within) and group (between) as factors was performed. Mean attendance was 75%, mean heart rate 104 bpm, mean perceived exertion 5.9 (1-10 scale) and enjoyment 4.4 (1-5 scale). There was a significant (P = 0.039) time by group interaction for BMI percentile. Graphs indicated that this difference was influenced by large reductions in the BMI percentile of healthy girls. Girls enjoyed Pilates, and participation for 4 weeks lowered BMI percentile. Pilates holds promise as a means of reducing obesity.

Segal et al., (2004) conducted a study on effects of Pilates training on flexibility, body composition, and health status: An observational prospective study. A community athletic club has taken a sample of 47 adults (45 women, 2 men) who presented for Pilates training. Fingertip-to-floor distance, truncal lean body mass by bioelectric impedance, health status by questionnaire and visual analog scale were assessed at baseline, 2, 4, and 6 months (+/-1 wk). Thirty-two of 47 enrolled subjects met the protocol requirements of missing no more than 1 weekly 1-hour session Pilates mat class during each 2-month period. Investigators were blinded to measurements from previous time points. Median (inter quartile range [IQR]) fingertip-to-floor distance improved from baseline by 3.4 cm (1.3-5.7 cm), 3.3 cm (0.3- 7.8 cm), and 4.3 cm (1.5-7.6 cm) at 2, 4, and 6 months, respectively (paired nonparametric analysis, all P<.01). There were no statistically significant changes in truncal lean body mass, height, weight, or other body composition parameters. Self-assessment of health also did not change in a statistically significant manner from its baseline median (IQR) value of 77 mm (69-85 mm). Pilates training may result in improved flexibility. However, its effects on body composition, health status, and
posture are more limited and may be difficult to establish. Further study might involve larger sample sizes, comparison with an appropriate control group, and assessment of motor unit recruitment as well as strength of truncal stabilizers.

### 2.3 STUDIES RELATED ON PNF STRETCH TECHNIQUE

Miyahara et al., (2012) conducted a study effect of proprioceptive neuromuscular facilitation stretching and static stretching on maximal voluntary contraction. This study was undertaken to investigate and compare the effects of proprioceptive neuromuscular facilitation (PNF) stretching and static stretching on maximal voluntary contraction (MVC). Thirteen male university students (age, 20 ± 1 years; height, 172.2 ± 4.6 cm; weight, 68.4 ± 6.7 kg; mean ± SD) completed three different conditions on three non-consecutive days in randomized order: static stretching (SS), PNF stretching (PNF), and no stretching (control, CON). Each condition consisted of a 5-minute rest accompanied by one of the following activities: (a) control, (b) static stretching, or (c) PNF stretching. The hip flexion range of motion (ROM) was evaluated immediately before and after the activity. The MVC of knee flexion was then measured. Surface electromyography was recorded from the biceps femoris and vastuslateralis muscles during MVC tests and stretching. Although increases in ROM were significantly greater after PNF than after SS (P < 0.01), the decreases in MVC were similar between the two treatments. These results suggest that, although PNF stretching increases ROM more than static stretching, PNF stretching as well as static stretching is detrimental to isometric maximal strength.

Herda et al., (2011) conducted a study on effects of two modes of static stretching on muscle strength and stiffness. The purpose of the present study was to examine the effects of constant-angle (CA) and constant-torque (CT) stretching of the leg flexors on peak torque (PT), EMGRMS at PT, passive range of motion (PROM), passive torque (PAS(TQ)), and musculotendinous stiffness (MTS). Seventeen healthy men (mean ± SD: age = 21.4 ± 2.4 yr) performed a PROM assessment and an isometric maximal voluntary contraction of the leg flexors at a knee joint angle of 80° below full leg extension before and after 8 min of CA and CT stretching. PASTQ and
MTS were measured at three common joint angles for before and after assessments. PT decreased (mean ± SE = 5.63 ± 1.65 N·m) (P = 0.004), and EMG(RMS) was unchanged (P > 0.05) from before to after stretching for both treatments. PROM increased (5.00° ± 1.03°) and PASTQ decreased at all three angles before to after stretching (angle 1 = 5.03 ± 4.52 N·m, angle 2 = 6.30 ± 5.88 N·m, angle 3 = 6.68 ± 6.33 N·m) for both treatments (P ≤ 0.001). In addition, MTS decreased at all three angles (angle 1 = 0.23 ± 0.29 N·m·°(-1), angle 2 = 0.26 ± 0.35 N·m·°(-1), angle 3 = 0.28 ± 0.44 N·m·°(-1)) after the CT stretching treatment (P < 0.005); however, MTS was unchanged after CA stretching (P > 0.05). PT, EMG(RMS), PROM, and PASTQ changed in a similar manner after stretching treatments; however, only CT stretching resulted in a decrease in MTS. Therefore, if the primary goal of the stretching routine is to decrease MTS, these results suggest that CT stretching (constant pressure) may be more appropriate than a stretch held at a constant muscle length (CA stretching).

Liu et al., (2011) conducted a study on treatment of complex elbow injuries with a postoperative custom-made progressive stretching static elbow splint. Complex elbow injuries consist of fractures of one or several of the bony stabilizers of the elbow, including the radial head, proximal ulna, coronoid process, collateral ligaments, and capsular complex. These injuries, if not properly treated, were reported to have a poor prognosis with recurrent instability, stiffness, posttraumatic arthrosis, and pain. This study was conducted to review clinical outcomes after fracture stabilization and ligament repair with a postoperative custom-made progressive stretching (CMPS) elbow splint in the treatment of complex elbow injuries. From December 2001 to October 2006, 14 patients with complex elbow fractures or instability underwent surgery in Far Eastern Memorial Hospital by Chang Chih-Hung, using suture anchors. All patients used our CMPS static elbow splint postoperatively. No hinged elbow external skeletal fixator was necessary. The results were reviewed retrospectively. The patients were followed up for an average of 14 months. The mean (standard deviation) flexion-extension range of motion (ROM) was 116-degree angle (23-degree angle). The mean Mayo Elbow Performance Score was 92 points;
The results were excellent in 10 patients, good in three patients, and fair in one patient. The dilemma in managing complex elbow injuries is that extended immobilization leads to stiffness, but without proper reconstruction of the stabilizer, joint instability recurs. Our surgical protocol included removal of all loose bodies within the joint, stable fixation of fracture fragments if possible, and use of suture anchors to repair medial or lateral lunar collateral ligaments. CMPS static elbow splints provided both postoperative protection and ROM movement. In our experience, if the stabilizers were reconstructed, hinged elbow external skeletal fixator is usually not necessary, and progressive stretching by CMPS splint can result in good ROM.

Gomes et al., (2011) conducted a study on acute effects of two different stretching methods on local muscular strength endurance performance. The purpose of this study was to assess the acute effects of the static and proprioceptive neuromuscular facilitation (PNF) stretching methods on local muscular strength endurance performance at intensities between 40 and 80% of 1 repetition maximum (1RM) for the knee extension (KE) and bench press (BP) exercises. Fifteen male volunteers (23.9 ± 4.3 years; 174.5 ± 8.5 cm; and 77.8 ± 7.6 kg), who were non-athletes but had previous experience in resistance training, volunteered for this study. Participants were assigned to 9 randomly ordered experimental conditions, in which all subjects performed endurance tests at 40, 60, and 80% of 1RM, preceded by static stretching (SS), PNF, and no stretching (NS) in the KE and BP exercises. One-way repeated-measures analysis of variance (NS × SS × PNF) revealed an influence of stretching for all intensities only when the PNF treatment was used. Significant differences (p < 0.05) were found in the KE exercise, with reductions in the number of repetitions when comparing PNF40 (23.7 ± 2.7) to NS40 (27.5 ± 3.6); PNF60 (12.6 ± 2.8) to SS60 (16.5 ± 4.1) and NS60 (17.3 ± 3.2); and PNF80 (6.3 ± 1.7) to SS80 (9.9 ± 2.5) and NS80 (9.8 ± 2.3) conditions. Significant differences (p < 0.05) were also found for the BP exercise with decreases in the number of repetitions when comparing PNF60 (13.7 ± 2.8) to NS60 (17.0 ± 3.0) and PNF80 (6.2 ± 2.2) to NS80 (8.7 ± 2.3) conditions. These findings suggest that for the intensities studied (40, 60, and 80% 1RM), only the PNF method decreased muscle endurance. Strength and
conditioning professionals may want to consider avoiding PNF stretching before activities requiring local muscular strength endurance performance.

**Marangoni et al., (2010)** conducted a study effects of intermittent stretching exercises at work on musculoskeletal pain associated with the use of a personal computer and the influence of media on outcomes. The objective of this study was to evaluate the effects of regular stretching exercises on pain associated with working at a computer workstation, and to ascertain whether the type of media used for exercise instruction had an effect on outcomes. Sixty-eight volunteers were divided into three equivalent groups. All of the subjects worked at computers for prolonged periods of time and reported that their pain had been a source of distress for at least three weeks prior to the intake evaluation. A pretest-posttest-control group design with cluster randomization was used to evaluate the effect of a stretching program on pain. Thirty-six different stretches were performed by the subjects for 15-17 work days. Two intervention groups were directed to stretch once every six minutes. One group (n=22) was reminded to stretch via a computer program, the second group (n=23) by using a hard copy version of the stretches with pictures and written instructions, and a third group received no intervention. NOVA analysis found a significant reduction in pain of 72% (p < 0.001) for the computer-generated stretching program, and of 64% (p < 0.001) using the hardcopy version of the intervention. The control group had an increase in pain of 1%. Both software and hard copy stretching interventions contributed to a decrease in pain without making any changes to workstation ergonomics and there was no significant statistical difference in the outcomes of either intervention. The subjective evaluation of pain using both visual analog scales and a newly created "pain spot" assessment technique yielded similar results.

**Aquino et al., (2010)** conducted a study on effect of stretching versus strength training in lengthened position in subjects with tight hamstring muscles: a randomized controlled trial. Stretching is used to modify muscle length. However, its effects seem to be temporary. There is evidence in animal models that strengthening in a lengthened position may induce long lasting changes in muscle length. The objective of this study was to compare changes in hamstrings flexibility, peak torque angle and
stretch tolerance after two training programs: stretching and strengthening in a lengthened position. Forty-five subjects with tight hamstrings were randomly assigned into three groups: control, stretching and strength training in lengthened position. The interventions were performed three times a week for eight weeks. The subjects were assessed before and after the end of the programs. Data provided by an isokinetic dynamometer were used to assess hamstrings flexibility, peak torque angle, and stretch tolerance. The data analysis demonstrated that strengthening in lengthened position changed peak torque angle in the direction of knee extension (p=0.001). No change in flexibility was observed (p=0.449). Both experimental groups showed an increase in stretch tolerance (p=0.001). The results demonstrated that strengthening in a lengthened position produced a shift of the torque-angle curve, which suggests an increase in muscle length. Conversely, stretching did not produce modification of torque-angle curve and flexibility; its effects appear restricted to increases in stretch tolerance.

Marques et al., (2009) conducted a study on effect of frequency of static stretching on flexibility, hamstring tightness and electromyographic activity. We compared the effect of the number of weekly repetitions of a static stretching program on the flexibility, hamstring tightness and electromyographic activity of the hamstring and of the triceps surae muscles. Thirty-one healthy subjects with hamstring tightness, defined as the inability to perform total knee extension, and shortened triceps surae, defined by a tibiotarsal angle wider than 90 degrees during trunk flexion, were divided into three groups: G1 performed the stretching exercises once a week; G2, three times a week, and G3, five times a week. The parameters were determined before and after the stretching program. Flexibility improved in all groups after intervention, from 7.65 +/- 10.38 to 3.67 +/- 12.08 in G1, from 10.73 +/- 12.07 to 0.77 +/- 10.45 in G2, and from 14.20 +/- 10.75 to 6.85 +/- 12.19 cm in G3 (P < 0.05 for all comparisons). The increase in flexibility was higher in G2 than in G1 (P = 0.018), while G2 and G3 showed no significant difference (G1: 4 +/- 2.17, G2: 10 +/- 5.27; G3: 7.5 +/- 4.77 cm). Hamstring tightness improved in all groups, from 37.90 +/- 6.44 to 29 +/- 11.65 in G1, from 39.82 +/- 9.63 to 21.91 +/- 8.40 in G2, and from 37.20 +/-
6.63 to 26.10 +/- 5.72 degrees in G3 (P < 0.05 for all comparisons). During stretching, a statistically significant difference was observed in electromyographic activity of biceps femoris muscle between G1 and G3 (P = 0.048) and G2 and G3 (P = 0.0009). No significant differences were found in electromyographic activity during maximal isometric contraction. Stretching exercises performed three times a week were sufficient to improve flexibility and range of motion compared to subjects exercising once a week, with results similar to those of subjects who exercised five times a week.

Bacurau et al., (2009) conducted a study on acute effect of a ballistic and a static stretching exercise bout on flexibility and maximal strength. Different stretching techniques have been used during warm-up routines. However, these routines may decrease force production. The purpose of this study was to compare the acute effect of a ballistic and a static stretching protocol on lower-limb maximal strength. Fourteen physically active women (169.3 +/- 8.2 cm; 64.9 +/- 5.9 kg; 23.1 +/- 3.6 years) performed three experimental sessions: a control session (estimation of 45 degrees leg press one-repetition maximum [1RM]), a ballistic session (20 minutes of ballistic stretch and 45 degrees leg press 1RM), and a static session (20 minutes of static stretch and 45 degrees leg press 1RM). Maximal strength decreased after static stretching (213.2 +/- 36.1 to 184.6 +/- 28.9 kg), but it was unaffected by ballistic stretching (208.4 +/- 34.8 kg). In addition, static stretching exercises produce a greater acute improvement in flexibility compared with ballistic stretching exercises. Consequently, static stretching may not be recommended before athletic events or physical activities that require high levels of force. On the other hand, ballistic stretching could be more appropriate because it seems less likely to decrease maximal strength.

Rowlands et al., (2009) conducted a study on chronic flexibility gains: effect of isometric contraction duration during proprioceptive neuromuscular facilitation stretching techniques. The aim of this study was to assess the effect of isometric contraction durations during proprioceptive neuromuscular facilitation stretching on gains in flexion at the hip. Forty-three women (M age = 20.0 years, SD = 1.3) were
assigned to one of three groups: 5-s isometric contraction (5-IC), 10-IC, and control. Flexibility was assessed at baseline and Weeks 3 and 6. Analysis of covariance, controlling for pretest differences, showed a significant interaction, F(2, 33) = 44.1, p < .001. Flexibility was significant lower in the control group relative to the 5-IC and 10-IC groups and in the 5-IC group relative to the 10-IC group at 3 and 6 weeks (3 weeks = 101.2 +/- 1.4 degrees, 114.3 +/- 1.5 degrees, 120.5 +/- 1.3 degrees; 6 weeks = 103.0 +/- 1.4 degrees, 126.1 +/- 1.6 degrees, 133.3 +/- 1.4 degrees for control, 5-IC and 10-IC groups, respectively). A longer contraction time led to greater increases in flexibility.

Manoel et al., (2008) conducted a study on acute effects of static, dynamic, and proprioceptive neuromuscular facilitation stretching on explosive power in women. The purpose of this study was to investigate the acute effects of 3 types of stretching-static, dynamic, and proprioceptive neuromuscular facilitation (PNF)-on peak explosive power output in women. Concentric knee extension power was measured isokinetically at 60 degrees x s(-1) and 180 degrees x s(-1) in 12 healthy and recreationally active women (mean age +/- SD, 24 +/- 3.3 years). Testing occurred before and after each of 3 different stretching protocols and a control condition in which no stretching was performed. During 4 separate laboratory visits, each subject performed 5 minutes of stationary cycling at 50 W before performing the control condition, static stretching protocol, dynamic stretching protocol, or PNF protocol. Three sub-maximal warm-up trials preceded 3 maximal knee extensions at each testing velocity. A 2-minute rest was allowed between testing at each velocity. The results of the statistical analysis indicated that none of the stretching protocols caused a decrease in knee extension power. Dynamic stretching produced percentage increases (8.9% at 60 degrees x s(-1) and 6.3% at 180 degrees x s(-1)) in peak knee extension power at both testing velocities that were greater than changes in power after static and PNF stretching. The findings suggest that dynamic stretching may increase acute muscular power to a greater degree than static and PNF stretching. These findings may have important implications for athletes who participate in events that rely on a high level of muscular power.
Franco et al., (2008) conducted a study on acute effect of different stretching exercises on muscular endurance. This study aims to evaluate the acute effects of different stretching exercises on muscular endurance in men, in terms of the number of sets, set duration, and type of stretching. Two experiments were conducted; in the first one (E1), the subjects (n = 19) were evaluated to test the effect on the number of sets, and, in the second one (E2), the subjects (n = 15) were tested for the effect of set duration and type of stretching. After a warm-up of 10-15 repetitions of a bench press (BP) with sub maximal effort, a one-repetition maximum (1RM) test was applied. For E1, BP endurance was evaluated after static stretching comprising one set of 20 seconds (1 x 20), two sets of 20 seconds (2 x 20), and three sets of 20 seconds (3 x 20). For E2, BP endurance was evaluated after static stretching comprising one set of 20 seconds (1 x 20), one set of 40 seconds (1 x 40), and proprioceptive neuromuscular facilitation (PNF) stretching. All tests were performed 48-72 hours apart, at which time the muscular endurance was assessed through the maximal number of repetitions (NR) of BP at 85% of 1RM until fatigue. The NR and the overload volume (OV) were compared among tests through repeated-measures analysis of variance. No significant effect of the number of sets on muscular endurance was observed because no statistically significant difference was found when comparing all stretching exercises of E1 in terms of NS (p = 0.5377) and OV (p = 0.5723). However, significant reductions were obtained in the set duration and PNF on NR (p < 0.0001) and OV (p < 0.0001), as observed in E2. The results suggest that a stretching protocol can influence BP endurance, whereas a decrease in endurance is suggested to be attributable to set duration and PNF. On the other hand, a low volume of static stretching does not seem to have a significant effect on muscular endurance.

Cunha et al., (2008) conducted a study on effect of global posture reeducation and of static stretching on pain, range of motion, and quality of life in women with chronic neck pain: a randomized clinical trial. Compare the effect of conventional static stretching and muscle chain stretching, as proposed by the global posture reeducation method, in the manual therapy of patients with chronic neck pain. Thirty-three female patients aged 35 to 60 years old, 31 of whom completed the program,
were randomly divided into two groups: The global posture reeducation group (n=15) performed muscle chain stretching, while the conventional stretching group (n=16) performed conventional static muscle stretching. Both groups also underwent manual therapy. Patients were evaluated before and after treatment and at a six-week follow-up appointment and tested for pain intensity (by means of visual analog scale), range of motion (by goniometry), and health-related quality of life (by the SF-36 questionnaire). The treatment program consisted of two 1-hour individual sessions per week for six weeks. Data were statistically analyzed at a significance level of p<0.05. Significant pain relief and range of motion improvement were observed after treatment in both groups, with a slight reduction at follow-up time. Quality of life also improved after treatment, except for the global posture reeducation group in one domain; at follow-up, there was improvement in all domains, except that both groups reported increased pain. There were no significant differences between groups Conventional stretching and muscle chain stretching in association with manual therapy were equally effective in reducing pain and improving the range of motion and quality of life of female patients with chronic neck pain, both immediately after treatment and at a six-week follow-up, suggesting that stretching exercises should be prescribed to chronic neck pain patients.

Beedle et al., (2008) conducted a study on pretesting static and dynamic stretching does not affect maximal strength. The purpose of this study was to determine whether there was a significant difference in static stretching (SS), dynamic stretching (DS), and no stretching (NS) on maximal strength (one-repetition maximum [1RM]) in the bench and leg presses using free weights on 19 college-aged men and 32 women. Most of the participants were moderately to very active and had previous experience with weight training. The design was repeated measures, with each treatment being randomly assigned. Each testing session was separated by 72 hours. Moderate-intensity stretching was defined as stretching as far as possible without any assistance, and subjects were encouraged to do their best. For the SS routine, the chest, shoulder, triceps, quadriceps, and hamstrings were stretched. Three repetitions were performed for 15 seconds, each separated by a 10-second rest. For
DS, the upper-body stretch was swinging each arm, one at a time, as far forward and then as far backward as possible in a diagonal plane. For the legs, the same movement was done for each leg, except performed in a sagittal plane. Each forward and backward movement took about 2 seconds. Three 30-second sets were administered, and a 10-second rest was allowed between sets. Next, 1RM was determined for the bench and leg presses in random order. Two warm-up sets were given, followed by several 1RM attempts. The last successful lift was recorded as the 1RM. Data were reported using means +/- SD. A one-way ANOVA with repeated measures was used with alpha set at 0.05. There was no significant difference among the treatments. Moderate-intensity stretching does not seem to adversely affect 1RM in the bench and leg presses.

**Jaggers et al., (2008)** conducted a study on acute effects of dynamic and ballistic stretching on vertical jump height, force, and power. Stretching before performance is a common practice among athletes in hopes of increasing performance and reducing the risk of injury. However, cumulative results indicate a negative impact of static stretching and proprioceptive neuromuscular facilitation (PNF) on performance; thus, there is a need for evaluating other stretching strategies for effective warm-up. The purpose of this study was to compare the differences between two sets of ballistic stretching and two sets of a dynamic stretching routine on vertical jump performance. Twenty healthy male and female college students between the ages of 22 and 34 (24.8 +/- 3 years) volunteered to participate in this study. All subjects completed three individual testing sessions on three nonconsecutive days. On each day, the subjects completed one of three treatments (no stretch, ballistic stretch, and dynamic stretch). Interclass reliability was determined using the data obtained from each subject. A paired samples t-test revealed no significant difference in jump height, force, or power when comparing no stretch with ballistic stretch. A significant difference was found on jump power when comparing no stretch with dynamic stretch, but no significant difference was found for jump height or force. Statistics showed a very high reliability when measuring jump height, force, and power using the Kistler Quattro Jump force plate. It seems that neither dynamic stretching nor
ballistic stretching will result in an increase in vertical jump height or force. However, dynamic stretching elicited gains in jump power post stretch.

Rees et al., (2007) conducted a study on effects of proprioceptive neuromuscular facilitation stretching on stiffness and force-producing characteristics of the ankle in active women. The purpose of this study was to examine the effect of proprioceptive neuromuscular facilitation (PNF) stretching on musculotendinous unit (MTU) stiffness of the ankle joint. Twenty active women were assessed for maximal ankle range of motion, maximal strength of planter flexors, rate of force development, and ankle MTU stiffness. Subjects were randomly allocated into an experimental (n = 10) group or control group (n = 10). The experimental group performed PNF stretching on the ankle joint 3 times per week for 4 weeks, with physiological testing performed before and after the training period. After training, the experimental group significantly increased ankle range of motion (7.8%), maximal isometric strength (26%), rate of force development (25%), and MTU stiffness (8.4%) (p< 0.001). Four weeks of PNF stretching contributed to an increase in MTU stiffness, which occurred concurrently with gains to ankle joint range of motion. The results confirm that MTU stiffness and joint range of motion measurements appear to be separate entities. The increased MTU stiffness after the training period is explained by adaptations to maximal isometric muscle contractions, which were a component of PNF stretching. Because a stiffer MTU system is linked with an improved ability to store and release elastic energy, PNF stretching would benefit certain athletic performance due to a reduced contraction time or greater mechanical efficiency. The results of this study suggest PNF stretching is a useful modality at increasing a joint's range of motion and its strength.

Zakas et al., (2006) conducted a study to investigate the acute effects of static stretch on the range of motion (ROM) of the lower extremities and trunk in elderly women, when stretching is performed with and without warming-up exercises. Twenty-two sedentary subjects 65-85 years old (mean age: 76.5 years) with normal ROM without joint abnormalities took part in the study, and performed 3 different flexibility protocols in non-consecutive randomized sessions. The first stretching
protocol comprised of a general warming-up for 20 min, the second of the same
general warming-up followed by static stretching of the lower extremities and the
trunk, whereas the third and final stretching protocol consisted of static stretching
alone. Passive ROM was examined at the lower extremity joints and trunk flexion,
using a goniometer and a flexometer. Static stretching alone and static stretching after
a general warming-up bout, significantly increased the range of all lower extremity
joints and trunk flexion (P<0.001). The general warming-up session included a
significantly increased ROM only at the ankle dorsiflexion joint (P<0.001). The
results reflect immediate changes in flexibility via acute stretching exercises, in
sedentary elderly women, when muscles undergo static elongation, irrespective of the
performance of warming-up exercises.

Brandenburg (2006) conducted a study on duration of stretch does not
influence the degree of force loss following static stretching. There is an emerging
body of knowledge indicating static stretching (SS) acutely and adversely affects
muscle performance. The practical value of this research is limited considering the
lengthy stretch durations under investigation. It is unclear if stretch durations typical
of those used pre-exercise similarly affect muscle performance. The purpose of this
study was to determine if SS using more representative stretch durations affects
muscle performance and to establish if changes in muscle performance were
influenced by the duration of stretch. Following 2 familiarization sessions, 16
recreationally trained males and females participated in 2 randomly ordered
experimental sessions. In each session maximal effort hamstring performance was
assessed prior to and immediately after 1 of 2 stretching protocols. During one of the
protocols participants were required to hold each stretch for 15 s while stretch
duration in the second protocol was 30 s. Both protocols consisted of 3 repetitions of
2 stretching exercises. A Kincom isokinetic dynamometer was used to assess
hamstring performance during isometric, concentric, and eccentric actions. For each
of the three muscle actions a repeated measures ANOVA revealed a significant main
effect of time (pre- vs post stretch, P<0.05) but no interaction effect (time x SS
protocol). Furthermore, the stretch-induced deficits in muscle performance were
consistent across muscle action type. SS incorporating stretch durations typical of those employed pre-exercise were sufficient to impair muscle performance and the duration of stretch did not influence the degree of force loss. Inclusion of SS, even with short stretch durations, in preparation for strength activities is not appropriate.

**Borstad et al., (2006)** conducted a study on Comparison of three stretches for the pectoralis minor muscle. Pectoralis minor adaptive shortening in healthy individuals is associated with altered scapular kinematics similar to the alterations demonstrated in individuals with subacromial impingement. This associative relationship suggests that stretching of the pectoralis minor may improve scapular kinematics and assist in the management of shoulder impingement. Several stretches for the pectoralis minor are used clinically, although it is not known which stretch optimally lengthens the muscle. The purpose of this analysis was to compare the mean length change for 3 pectoralis minor stretches. Fifty subjects without shoulder pathology were examined for the change in length of the pectoralis minor during 3 separate stretches by use of an electromagnetic motion-capture system. The stretches analyzed were a unilateral self-stretch a supine manual stretch, and a sitting manual stretch. Each stretch was significantly different from the other two (df, 2/98; F ratio, 39.09; P < .00001), with the unilateral self-stretch demonstrating the greatest length change (2.24 cm), followed by the supine manual stretch (1.69 cm) and the sitting manual stretch (0.77 cm). Knowledge of the most effective method of elongating the pectoralis minor muscle may improve clinical decision making when targeting this anterior scapulothoracic muscle as part of intervention for or prevention of shoulder impingement.

**Davis et al., (2005)** conducted a study on the effectiveness of 3 stretching techniques on hamstring flexibility using consistent stretching parameters. This study compares the effects of 3 common stretching techniques on the length of the hamstring muscle group during a 4-week training program. Subjects were 19 young adults between the ages of 21 and 35. The criterion for subject inclusion was tight hamstrings as defined by a knee extension angle greater than 20 degrees while supine with the hip flexed 90 degrees. The participants were randomly assigned to 1 of 4
groups. Group 1 (n = 5) was self-stretching, group 2 (n = 5) was static stretching, group 3 (n = 5) was proprioceptive neuromuscular facilitation incorporating the theory of reciprocal inhibition (PNF-R), and group 4 (n = 4) was control. Each group received the same stretching dose of a single 30-second stretch 3 days per week for 4 weeks. Knee extension angle was measured before the start of the stretching program, at 2 weeks, and at 4 weeks. Statistical analysis (p ≤ 0.05) revealed a significant interaction of stretching technique and duration of stretch. Post hoc analysis showed that all 3 stretching techniques increase hamstring length from the baseline value during a 4-week training program; however, only group 2 (static stretching) was found to be significantly greater than the control at 4 weeks. These data indicate that static stretching 1 repetition for 30 seconds 3 days per week increased hamstring length in young healthy subjects. These data also suggest that active self-stretching and PNF-R stretching 1 repetition for 30 seconds 3 days per week is not sufficient to significantly increase hamstring length in this population.

Pollard et al., (1997) conducted a study on a study of two stretching techniques for improving hip flexion range of motion. A reliable hand-held dynamometer was used to determine the end point of range of motion (ROM) before and after the application of a treatment. Three groups of subjects were treated: cervical stretch, hip stretch and sham/placebo. ROM of the hip in flexion (straight leg raise) was used as the independent variable. Sixty randomly allocated university students aged between 18 and 35 yr. The two stretching treatments resulted in increased flexion ROM at the hip. Statistical analysis revealed that only the suboccipital stretching procedure increased hip flexion ROM significantly. Manual therapy of the neck may have a role to play in the treatment of extra spinal, lower-limb musculoskeletal conditions.

Webright et al., (1997) conducted a study on Comparison of nonballistic active knee extension in neural slump position and static stretch techniques on hamstring flexibility. Nonballistic, active range of motion exercises have been advocated as more effective than static stretching for increasing range of motion, yet no published data exist to support this claim. This study compared the effect of
nonballistic, repetitive active knee extension movements performed in a neural slump sitting position with static stretching technique on hamstring flexibility. Forty healthy, adult volunteer subjects with limited right hamstring flexibility (i.e., minimum of 15 degrees loss of active knee extension measured with femur held at 90 degrees of hip flexion) were randomly assigned to one of three groups. Group 1 (static stretch) performed a 30-second stretch twice daily. Group 2 (active stretch) performed 30 repetitions of active knee extension while sitting in a neural slump position twice daily. Group 3 served as a control. Hamstring flexibility was determined by an active knee extension test before and after 6 weeks of stretching. Goniometric measurement of knee joint flexion angle was obtained from videotape recording of the active knee extension test. A 3 (group) x 2 (test) repeated measures analysis of variance and subsequent Turkey post hoc testing revealed no significant difference in knee joint range of motion gains between the static (mean = 8.9 degrees) and active stretch (mean = 10.2 degrees). Both stretch groups' knee joint range of motion improved significantly (p < .05) more than the control group. We conclude that 6 weeks of nonballistic, repetitive active knee extensions (30 repetitions, twice daily) performed in a neural slump sitting position improves hamstring flexibility in uninjured subjects, but is no different compared with static stretching (30 seconds, twice daily).

Cornelius et al., (1995) conducted a study on effects of PNF stretching phases on acute arterial blood pressure. This study examined acute systolic (SBP) and diastolic (DBP) blood pressure responses within passive and modified proprioceptive neuromuscular facilitation (PNF) stretching techniques. Non hypertensive (N = 60) were assigned to one of three treatment groups. Group 1 employed an antagonist passive stretch (APS), 6-sec maximal voluntary isometric contraction (MVIC) of the antagonist, and subsequent APS. Group 2 employed an APS, a 6-sec MVIC of the antagonist, submaximal concentric contraction of the agonist, and APS. Group 3 was similar to Group 2, with the deletion of an MVIC prior to the concentric contraction. Blood pressures were obtained during rest, baseline following passive stretch, and at the end of the three phases of the PNF technique. Range of motion (ROM) data were collected for baseline and treatment in terminal hip flexion for each group. All PNF
treatments were effective for increasing ROM. One or two trials of PNF improve ROM and avoid increasing SBP, while a third trial increases SBP.

**Molacek et al., (2010)** conducted a study to determine the effects of acute low- and high-volume static and proprioceptive neuromuscular facilitation (PNF) stretching on 1-repetition maximum (1RM) bench press. Fifteen healthy male National Collegiate Athletic Association Division II football players (age: 19.9 +/- 1.1 years; weight: 98.89 +/- 13.39 kg; height: 184.2 +/- 5.7 cm; body composition: 14.6 +/- 7.4%; and 1RM bench press: 129.7 +/- 3.3 kg) volunteered to participate in the study. Subjects completed 5 different stretching protocols integrated with a 1RM dynamic warm-up routine followed by 1RM testing in randomly assigned order. The protocols included (a) nonstretching (NS), (b) low-volume PNF stretching (LVPNFS), (c) high-volume PNF stretching (HVPNFS), (d) low-volume static stretching (LVSS), and (d) high-volume static stretching (HVSS). Two and 5 sets of stretching were completed for the low- and high-volume protocols, respectively. The stretching protocols targeted triceps and chest/shoulder muscle groups using 2 separate exercises. There were no significant differences in 1RM bench press performance (p > 0.05) among any of the stretching protocols NS (129.7 +/- 3.3 kg), LVPNFS (128.9 +/- 3.8 kg), HVPNFS (128.3 +/- 3.7 kg), LVSS (129.7 +/- 3.7 kg), and HVSS (128.2 +/- 3.7 kg). We conclude that low- and high-volume PNF and static stretching have no significant acute effect on 1RM bench press in resistance-trained collegiate football players. This suggests that resistance-trained athletes can include either (a) a dynamic warm-up with no stretching or (b) a dynamic warm-up in concert with low- or high-volume static or PNF flexibility exercises before maximal upper body isotonic resistance-training lifts, if adequate rest is allowed before performance.

**Kubo et al., (2002)** conducted a study to examine whether resistance and stretching training programmes altered the viscoelastic properties of human tendon structures in vivo. Eight subjects completed 8 weeks (4 days per week) of resistance training which consisted of unilateral plantar flexion at 70 % of one repetition maximum with 10 repetitions per set (5 sets per day). They performed resistance training (RT) on one side and resistance training and static stretching training (RST;
10 min per day, 7 days per week) on the other side. Before and after training, the elongation of the tendon structures in the medial gastrocnemius muscle was directly measured using ultrasonography, while the subjects performed ramp isometric plantar flexion up to the voluntary maximum, followed by a ramp relaxation. The relationship between estimated muscle force ($F_m$) and tendon elongation ($L$) was fitted to a linear regression, the slope of which was defined as stiffness. The hysteresis was calculated as the ratio of the area within the $F_m$–$L$ loop to the area beneath the load portion of the curve. The stiffness increased significantly by 18.8 ± 10.4 % for RT and 15.3 ± 9.3 % for RST. There was no significant difference in the relative increase of stiffness between RT and RST. The hysteresis, on the other hand, decreased 17 ± 20% for RST, but was unchanged for RT. These results suggested that the resistance training increased the stiffness of tendon structures as well as muscle strength and size, and the stretching training affected the viscosity of tendon structures but not the elasticity.

**Chan et al., (2001)** conducted a study to investigate the effects of a static stretching program with different stretching protocols on the flexibility and passive resistance of the hamstrings of young adults. Forty healthy subjects (24 males and 16 females) aged 18 to 30 years were randomly assigned to one of four groups. The two training groups underwent static stretch training of the hamstrings either with a four-week protocol or with an eight-week protocol. The other two groups acted as control groups. A significant increase in flexibility of hamstrings was found in both of the two training groups ($P<0.05$). No difference was found in the range of motion gained between the two training groups. An increase in passive resistance at the corresponding maximal joint angle was only demonstrated in the four week training group ($P<0.05$). Both protocols are effective in terms of improving flexibility of hamstrings. However, if injury is reduced when there is relatively lower passive resistance at the end-of-range, then the eight-week training regimen would be recommended.